AN ELEMENTARY TEXT-BOOK

OF

AGRICULTURAL BOTANY

BY

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PREFACE

In attempting to give an account of the various problems of the life of a Plant in an elementary text book, the most simple and natural method appears to be to treat each member of the plant in turn, considering it concurrently in relation to its special functions. This plan formed the basis of a series of Extension Lectures, on Plant Life, which I delivered in Newcastle in 1890, and proved so successful a scheme that it has been adopted as the foundation of the present work.

This little book, in its special application to Agriculture, is intended for the use of Agricultural Students, but at the same time it forms an elementary text-book on General Botany which will be found suitable for those commencing the study of Botany. In any text-book on Agricultural Botany a great part must necessarily be devoted to the consideration of the principles of Vegetable Physiology, and these can only be thoroughly grasped after a knowledge of the structure of the plant has been obtained. It has therefore been found necessary to explain the nature and properties of plant cells, and their functions in different parts of the plant, together with other considerations which to some might appear to have no direct bearing upon our subject. Yet every problem of Plant Physiology is of importance in Agriculture, though in an elementary treatise only certain of them can

be considered which relate more especially to the cultivation of plants. Without a knowledge of the constituents of a plant's food, the part each one plays in the development of the plant, and the manner in which they are severally taken possession of, there is no guide for the application of manures and their analysis remains unintelligible. The questions of Food and Disease have been treated, not so fully as might be done, yet we hope in sufficient detail to give the principles which underlie successful manuring and the combating of disease—each of these questions would require a volume in itself without even then being exhaustively treated.

My aim in these few pages has been to lay a foundation which may serve to guide the future operations in the Field, and form a basis for intelligent trial and experiment. In these days of competition and struggle for existence every little tells, and the farmer who, understanding, can apply his knowledge, is more likely to succeed, than one who labours without the advantage of this knowledge.

It has been my endeavour to use as few technical terms as possible. Botany is often considered a science of names, and is frequently presented to the beginner in anything but an inviting form. The use of some technical terms is unavoidable to ensure perfect accuracy, but scientific knowledge is often expressed in needlessly technical language, which conveys little or no meaning to the ordinary student. It has been my aim to write as simply as possible.

In preparing this work reference has been made to the standard text-books on Botany, by Sachs, De Bary and Vines, and to the original writings of many authors, notably Woronin, Sir J. B. Lawes and Dr Gilbert, Marshall

Ward, and Frank. For the tables on the Determination of Grasses, and the definitions of many genera, I am indebted to Mr W. R. Hayward and Messrs Bell & Sons for permission to make use of the Botanist's Pocket Book. I have also to express my thanks to the various authors and publishers who have allowed me to use the illustrations; to Messrs Albert for figures 34, 35, 94, and 97; and to Messrs Hunter for the blocks of the grass "seeds" which they have kindly lent.

M. C. P.

NEWCASTLE-UPON-TYNE,
March 1893.

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AGRICULTURAL BOTANY.

CHAPTER I.

INTRODUCTORY.

THE world of living organisms which everywhere surrounds us is naturally divided into two great kingdoms—the Animal and the Vegetable.

The distinction between the more important groups of these two kingdoms is, at first sight, very considerable, and in the higher forms of each undoubtedly the divergence is wide, but if we consider the lower forms of life with which we are not familiar except when examined under the microscope, it is evident that Nature has not drawn any sharp line of demarcation, for there are several organisms of simple structure which the Botanist claims as plants and the Zoologist as belonging to the Animal kingdom, so difficult is it sometimes to determine the place to which some of these organisms should be assigned. Animals and Plants, then, have many characteristics in common; they require sufficient supplies of food, they require to be kept at certain temperatures, extremes in either case causing a cessation of some of the vital actions, or even death, and further, in all the important cases, they require supplies of

oxygen, which are generally taken from the air. Their aims, therefore, are necessarily identical in many particulars, and each organism, whether animal or vegetable, will pursue a similar course of conduct, using different means to attain the same end. The endeavour of each will be

1st. To secure its own food, and to protect itself from very numerous enemies.

2nd. To reproduce its kind, and then to protect its offspring, or furnish them with the means of self-protection. To supply them with a sufficient store for the development of their various parts until such time as they are strong enough or able to provide their own nourishment, and to take care of themselves.

It is mainly in the manner of absorbing food and in the nature of the substances which compose this food, that these two kingdoms are separated from each other. The plant, if supplied with the various elements required for its structure in the form of mineral matter, can perform all its various functions and can build up its own structure; though it must be borne in mind that this mineral matter must first be made soluble before it can be converted to the uses of the plant. The animal, on the other hand, requires that all its food should be presented to it in the organic form, that is to say, an animal can only thrive when its food is composed of either animal or vegetable matter; and hence there are many animals which live entirely on other animals, and others which can subsist only when fed on plants. Thus a little thought will show the intimate relations existing between the two kingdoms, and how completely dependent the animal is upon the plant, for without plants there could be no animal existence.

The same chemical elements are employed in building up the structure of both animals and plants. If only one of these elements be absent starvation will result, even though all the others are available in abundance.

From what has been written above, it is evident that between the animal and plant world war is perpetually being waged; the plant, on the one hand, striving to protect itself from destruction, while the animal uses every endeavour to secure its food. Weapons of very various kinds are employed by the plant, while the animal, also, has many special contrivances to help it in this struggle. Further, the plant has not only to defend itself from various animals, but in many countries the climatic conditions are at certain seasons of the year hostile to vegetation, and special adaptations for protection are required under these conditions. As examples of the means of protection against animals, we may cite the thorns with which so many plants are armed, and which are specially developed to serve as weapons of defence. Familiar examples of protective thorns are afforded by the common Thistles, Whin, etc., but they are much more prevalent and formidable in desert countries where vegetation is scarce and animals are often very hard pressed for food, so that if the plants were undefended they would at once be destroyed. Many plants have an unpleasant taste, and not a few are poisonous, in order to prevent their being devoured by various animals.

It is especially the young and growing parts of a plant which are tender, and require protection from extremes of climate such as are experienced in the Tropics or the Arctic zones. But even in our own climate vegetation lies dormant during the winter months, and the leaves which are to expand in the next spring are covered up with

numerous specially formed protecting leaves, constituting the structures familiarly known as buds, and also many contrivances are employed to protect the expanding leaves in the spring from cold and in the summer from heat.

The duration of life in plants varies very much. Some are able to collect in one year sufficient stores of nutriment for their own use, and to place a sufficient store in each seed that the embryo may develop into a new plant. These plants, known as *Annuals*, live for a season, and die after ripening seed, to be succeeded by the next generation in the following year; they comprise many familiar weeds, Poppies, Charlock, Fumitory, etc.

Other plants—*Biennials*—divide their period of life into two years, the first of which is taken up with their own development, and the accumulation of nourishment, to be expended during the second year in the production of flowers and seed. The nutritive matter to be expended during the second year, known as *reserve material*, is stored up in various parts of the plant often very specially adapted for this purpose.

Others again, termed *Perennials*, live many years, during which they alternately accumulate and expend stores of reserve material in the same manner.

Each plant is an individual which requires light, warmth, air, and food. Part of its food it derives from the air, the remainder from the earth. Plants, therefore, which live close together must always be contending with each other, and enter into very fierce competition to secure these necessities from either source. Their roots penetrate into the ground and ramify in all directions, each seeking its own food supplies from the soil, whilst the leaves are ever striving with one another to secure a sufficiency of light

and air. So fierce is this struggle between plants in the wild state, that they have gradually become very highly specialised, and have evolved the various forms most peculiarly adapted to overcome their various enemies, and to secure their requirements under the particular conditions in which they live. But with cultivated plants, which have supplies of food given to them, the case is very different, and competition is to some extent reduced, especially under good cultivation, in which they are planted at such distances from each other that the competition is minimised, and weeds are not allowed to grow, which would otherwise deprive the soil of food substances intended for the crop.

In order to properly supply the plant with food, and to exercise a judicious selection of the most suitable cultivation for a particular soil, and therefore to obtain the best results from the cultivation of plants, a knowledge of all the various problems connected with plant life is necessary. With this aim in view the farmer should study the questions, How plants feed, What substances constitute their food, and How this food should be presented to them in order to ensure perfect health and immunity from disease.

We have spoken of the war between animals and plants and the means employed by plants to defend themselves, and also of the competition between plants growing very close together; but far more destructive to plant life are the unseen foes which on all sides attack them and cause disease. These unseen foes may be either minute animals, insect pests, which work such terrible destruction, or may be members of a group of plants known as Fungi, for example, moulds and mildew. The fungus, in the manner of obtaining its food, resembles an animal in so far as it can only live on organic matter, which may be either living

or dead: thus some fungi prey on living plants and cause often very serious diseases and heavy losses. Cultivated plants are specially liable to these attacks, when their health and consequent resisting power is in any way impaired by unfavourable seasons or bad cultivation.

The principle of the division of labour is well recognised in all branches of the arts and manufactures, but it is nowhere more strongly applied than in the animal and vegetable kingdoms. The various problems of plant economy necessitate that special parts of the plant should be set apart for the performance of very definite functions, and should be highly specialised for this purpose. This will be found not only in the external form, but also in the minute internal structure of each portion, which is so organised that its special work may be performed with the least possible expenditure of energy or waste of material.

A plant, laying aside all idea of the functions of its various parts, is usually said to consist of three members—the Root, the Stem, and the Leaf; under ordinary conditions each of these has its own work to do, but under special circumstances they may be altered and modified to serve some other purpose, so that they bear hardly any resemblance to the typical form. Branches may be altered into thorns as in the Sloe (*Prunus spinosa*), or modified into tubers as in the Potato, or Artichoke; leaves also may become thorns as in the Barberry (*Berberis vulgaris*); they may serve as the storehouse in which certain plants (*e.g.*, the Onion and Hyacinth) store up reserve material to be used in the following spring, or they may take part in the formation of the flower and aid in the process of reproduction; the root, again, may be utilised as the storehouse, familiar examples being presented in the Carrot and Parsnip.

Regarding the plant from another point of view, but without considering the manner in which its various parts are derived from the three typical members, it is made up of a number of organs each of which has some function to perform for which it is specially adapted. Seen in this light, roots are organs of attachment, and for absorbing food; stems are supports and conducting channels; leaves are manufactories; tubers and bulbs are storehouses; and thorns are weapons, etc., etc.

But in the succeeding chapters we shall trace the life of the plant in detail, considering the structure, functions, and modifications of each member. With these few considerations we have endeavoured to indicate merely the general conditions of plant life, to give an idea of the investigations required for the proper understanding of the various needs and requirements of plants. The student must recognise the value of enquiry and the necessity of scientific knowledge brought to bear upon plant cultivation, in order to produce better growth and development; for it is only when experience is based upon exact scientific knowledge that it has its full value, and the true nature of every success or failure can be understood.

CHAPTER II.

THE CELL.

IF a very thin section be cut from any part of one of the higher plants (for example, the stem of a Bean-plant) and magnified, it will be found not to be a solid structure, but to present a honey-combed appearance (see fig. 2). It is seen to be made up of a large number of small cavities of very different sizes, and shapes, some of which may be empty, while others are filled with various contents.

To these cavities the name cell was given when they were first discovered, hence the derivation of the word ; and the supporting framework was called the cell-wall. It was formerly thought that the cell-wall was the living part, but later researches have revealed the fact that it is a semifluid substance found closely adhering to the cell-wall in which life resides, and that the cell-wall is merely a framework made by this substance to support and protect it.

This living substance is termed *protoplasm*. By a plant cell we now mean a small mass of protoplasm, which may or may not have surrounded itself by a supporting cell-wall. This unicellular condition is found in several of the lower forms of vegetable life, but in only a few instances is the protoplasm exposed to the surrounding medium. In the higher forms, which are made up of a countless number of cells, the protoplasm always supports itself by a cell-wall.

We must now examine a cell more minutely, and will

take for example the illustration shown in fig. 1, which is that of a living mature plant cell. On the outside is

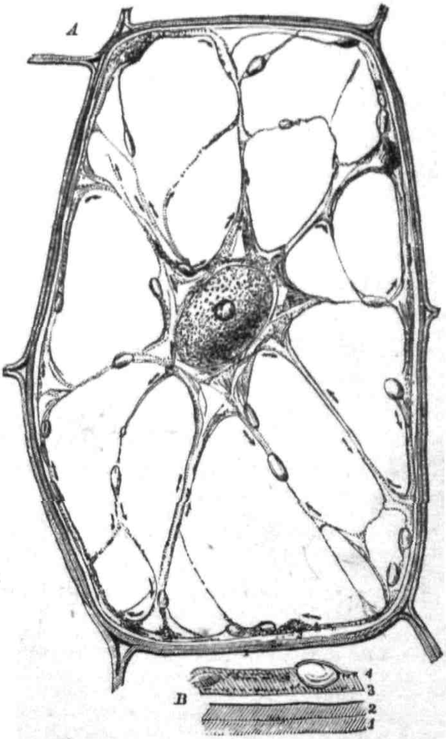


Fig. 1 (from Vines after Hanstein).

A, a typical living cell; *B*, a portion of cell-wall, and layer of protoplasm in contact with it more highly magnified; 1, 2, the common cell-wall of two adjacent cells; 3, ectoplasm; 4, granular endoplasm with chlorophyll corpuscles. The arrows indcate the direction of currents in the protoplasm.

seen the cell-wall, with here and there its junction with neighbouring cells, and this encloses the protoplasm which

is found as a thin layer in close contact with the cell-wall. This layer of protoplasm is divided into two portions, an outer one firm and clear, immediately inside the cell-wall, and an inner one which is granular and somewhat fluid: these are known respectively as the ectoplasm and the endoplasm. The space inside the layer of protoplasm, in contact with the cell-wall, contains a watery fluid known as *cell-sap*, and is traversed by numerous strands of protoplasm which divide it up into a number of smaller cavities, known as *sap-cavities*, or vacuoles. In the centre of the cell is an ovoid body, the *nucleus*, which these strands of protoplasm connect with the peripheral layer, and hold it in position.

The **Protoplasm** being the seat of all vital force, is therefore the essential part of every living cell, and without it there could be no life. It is a semifluid or gelatinous substance, white in colour, and of a granular appearance, and it has been found to possess all the functional activities which we regard as the characteristics of life.

We must now consider the properties and composition of protoplasm. A careful examination of a living cell will show that protoplasm is ever in motion (arrows in fig. 1), the peripheral layer is constantly moving round and round the cell, and the strands of protoplasm which connect the nucleus with the peripheral layer are also constantly moving to and from the nucleus. This motion originates in the protoplasm itself, and it is therefore said to be *automatic*.

It is only when subject to the right degree of temperature that protoplasm exhibits this activity—too great a degree of heat or cold paralyses it and stops the motion, and if these adverse conditions are continued, death ensues. Protoplasm is thus influenced by external conditions, and is said to be *irritable*.

Oxygen, which forms about one fourth of the atmosphere, is indispensable to vegetable life, and it is found that the protoplasm of every living cell is constantly absorbing oxygen, some of which combines with its carbon, and is given off as a colourless gas known as carbonic acid. The energy set free during this process, which is termed respiration, is used by the plant to perform its various functions. Respiration in the plant is not confined to one particular part, or to one group of cells, but every plant cell respires in a greater or less degree, and every plant cell must have within its reach a supply of oxygen in order to obtain its necessary amount of energy. Experiments have proved that in the absence of oxygen the activity of protoplasm ceases, and death follows, if it is deprived of this source of food for too long a period. Protoplasm is, therefore, *respiratory*.

Protoplasm is capable of absorbing into itself its various food substances, it is therefore *receptive*.

Further, it has the power of changing these substances into others which are more directly useful to it, and the waste products from this manufacture are expelled or got rid of by various means. This process of chemical change is described as *metabolism*, and may be considered under two heads; the first, *constructive*, in which complex organic substances are built up from inorganic ones, and converted into protoplasm; the second, *destructive*, in which protoplasm is broken up, some of the products being useful for constructive metabolism, others being merely waste.

It is found that in special regions of the plant there are cells which are capable of division to form new cells. The protoplasm of these cells divides, and forms a cell-wall across the original cell, and the cells so formed, after a

period of growth, may again divide. *Reproduction*, again, is thus one of the properties of protoplasm.

At the present time the exact chemical composition of protoplasm has not been determined. Living protoplasm is always in a state of change, due to its properties of respiring and absorbing its food substances into itself where they undergo chemical change, and for these reasons it is exceedingly difficult to obtain protoplasm in sufficient quantities in a pure state for analysis. But although no chemical formula can be assigned to protoplasm, yet it is always found to be made up of the five elements, Carbon, Oxygen, Hydrogen, Nitrogen, and Sulphur. In order, then, that a plant may produce new cells these five elements must be available.

Nucleus.—There is reason to believe that in every living plant cell a nucleus is present. The nucleus is an ovoid body embedded in protoplasm, and it may either be suspended in the centre of the cell or lie in the peripheral layer of protoplasm. In very young cells of the higher plants the nucleus (fig. 1) is a prominent feature, and in mature cells it is easily seen, but in many of the lower forms the presence of the nucleus can only be ascertained by the use of special reagents, and so for a long time it was thought to be absent in these cells.

Now, however, the most recent researches point to its universal presence in all plant cells.

The exact chemical composition of the nucleus, like that of the protoplasm, is at present not determined, but it appears to be composed of the same five elements which enter into the composition of protoplasm, but with the addition of Phosphorus.

The universal presence of a nucleus seems to point to

its being of some importance in the cell, but its exact functions are at present unknown.

The Cell-Wall.—We have seen that the protoplasm for the purposes of support and protection surrounds itself by a cell-wall, which may be either hard and rigid, or soft and flexible as in many low forms living in water. This cell-wall has a definite chemical composition, being made up of Carbon, Hydrogen, and Oxygen, which are combined together and form a substance known as cellulose, with the chemical formula $C_6H_{10}O_5$. The cell-wall is a product of the protoplasm itself, and is formed by the conversion of protoplasm into cellulose. This takes place in the outermost layer of protoplasm in contact with the cell-wall, and the increase in thickness of the latter is caused by the deposition of successive layers of cellulose.

The simplest forms of plants consist of only one cell, and the cell-wall therefore surrounds the protoplasm, but in the higher forms the protoplasm is divided up into very small masses by thin partitions of cell-wall, and these thin partitions must be regarded as common to the cells on either side of them. The cells are in connection one with another through minute pores in the dividing cell-wall, and the protoplasm, passing through these, is thus continuous throughout the whole plant, and we may therefore regard the plant as a mass of protoplasm chambered up into an infinite number of small compartments.

The cells which build up a plant have, when young, the power of growing, but this power is limited, so that when the maximum size has been attained further growth does not take place, and the plant, as a whole, increases in size by the formation of new cells.

The new cells are formed by the division of older cells,

that is, the nucleus divides into two nuclei and between these a cell-wall is formed; the mother cells thus divide into two daughter cells, and after a time these may divide again, or else grow to the full size and form part of the permanent structure of the plant. It is obvious that cells which have ceased to grow and those which are still in an active condition of growth must each be confined to definite parts of a plant. The regions of cell-division occur at the apex of the stem and root and at the growing portion of a leaf for the growth in length, and also a special zone of dividing cells encloses the stem or root when it has the power of increasing in thickness.

The life of a cell may be conveniently divided into three stages—(1) the stage when it is first formed; (2) the growing stage; and (3) the adult stage.

(1) The early stage when the cell has just been formed by the division of its mother cell, is very different from the mature condition, and it is then characterised by its thin cell-walls and by being completely full of protoplasm (fig. 9 *m w*), in which is embedded a large nucleus. It now begins to grow, and after a time may divide into two cells or may pass over into the second stage.

(2) In this stage the size and capacity of the cell are materially increased.

When a cell is so full of water that its walls are distended it is said to be turgid, and the turgidity of the cell is a necessary condition of growth. When the cell is turgid its volume is increased and the cell-wall becomes stretched. As the cell-wall stretches a fresh layer of cellulose is deposited upon it, and as it continues to extend successive layers of cellulose are again deposited upon the inner surface. It is in this manner that the cell-walls grow in length and the capacity of the cell becomes larger.

The volume of the protoplasm does not increase equally with that of the cell, and hence, after a time, numerous cavities are formed in it which become filled with a watery fluid known as cell-sap. As the cell increases in size these cavities also increase and coalesce to form several larger sap-cavities, in which case the nucleus becomes suspended at the centre of the cell by strands of protoplasm reaching from it to the protoplasm which adheres to the cell-wall (fig. 1); or the centre of the protoplasm may be occupied by one large sap-cavity and the nucleus lie embedded in the peripheral protoplasm.

(3) In the second stage the cell assumes its final shape and gradually reaches its full development; it then enters upon the third or mature stage and becomes a component part of the plant, and takes its part in the performance of the various functions which are allotted to it. The cell now ceases to grow, and therefore the cell-wall, being no longer stretched, it is possible for it now to increase considerably in thickness. When the cell-wall becomes much thickened the deposition of cellulose does not take place evenly over the whole surface, but small areas are left here and there which remain unthickened and are known as *pits*. Pits in the cell-wall are extremely common; they occur on each side of the common wall separating two cells, and it is through minute perforations at the bottom of these pits that the protoplasm of one cell is continuous with that on the other side of the dividing cell-wall.

In many of the mature cells which are found to be empty the protoplasm has all been expended in increasing the thickness of the cell-wall, and the cell, having lost its protoplasm, is therefore dead. Cells in this condition are, however, of great use in the plant economy, as they serve to

give strength to the plant and also act as channels through which water may be conducted.

The shape of a cell and the thickness of its walls depends on the particular function which it has to perform. In the very simple forms of plants, which consist of only one cell, it follows that all the various processes and work must be carried on in this cell, but in the multicellular plants there is a division of labour and special cells are set apart for special functions, some for nutrition, others for protection and support. We thus find that the cells assume very different shapes, but these are reducible to two types—(1) those which are approximately as long as broad, cubical or ovoid, and whose diameters are about equal (figs. 1 and 30); and (2) those which are longer than broad and have pointed ends (figs. 17 and 3, *a*).

The former are those which retain the living protoplasm and in which the various vital processes are carried on, and are termed *parenchymatous* cells; while the latter have generally very thick cell-walls and are specially adapted to build up those parts of a plant which are used as the supporting frame-work, these are termed *prosenchymatous* or mechanical cells.

In studying the anatomy of plants it is usual to find cells which are exactly alike grouped together, and investigation has shown that such cells have a common function. These masses of cells are known as tissues, and by a tissue we mean a group of cells which have a common origin, a common law of growth, and a common function.

The advantage derived from unity of cells for the purposes of nutrition and support is easily seen; in the case of support it is obvious that greater strength is derived from the union of a number of supporting cells.

It is usual to consider a plant as made up of three tissues though these, again, may be subdivided—viz., the epidermal, the ground, and the fibro-vascular tissues.

The **Epidermis** is the name given to those cells which entirely surround the plant, and from their position form a protective sheath covering the more tender cells which they enclose. This tissue is in most cases only one layer of cells in thickness, the outermost wall of each cell is often very much thickened, and for further protection the outermost layer of cellulose (in the parts exposed to the air) is transformed into a substance known as cutin, which forms a kind of waterproof covering to the whole plant.

The cells of the epidermis fit very closely together, and the only spaces formed between them are guarded by specially constructed cells. These guard cells are known as *stoma*, and will be further considered under the leaf. In annual plants the epidermis persists throughout the entire life of the plant, but in perennial plants its cells never have the power of dividing, and the epidermis is therefore torn or burst off and replaced by cells specially formed inside it, whose cell-walls are altered into a substance known as suberin and which forms cork or bark. Many plants are found to be hairy, some covered with long silky hairs while others have short and stiff hairs; these hairs are formed by single cells of the epidermis becoming elongated and projecting beyond the surface of the plant. Hairs are therefore defined as outgrowths of single epidermal cells. The hairs formed on stem and leaf serve in various ways to protect the plant, while those formed on the root (fig. 4) serve to abstract various food-substances from the soil.

Ground Tissue.—Those cells which are enclosed by the epidermis upon which they abut, and in which are placed

the fibro-vascular bundles, are known as the ground tissue. This tissue is composed of parenchyma and prosenchyma.

The cells of the parenchyma do not fit very closely together, but numerous spaces occur which are sometimes small, at other times relatively large, and these are known as intercellular spaces (figs. 30, *i* and 11).

From what has been already said it will be understood that the spaces are not formed simultaneously with the cells themselves, but that they are developed later during the growth of the cell, by the common wall of certain cells dividing and the two portions separating from each other. The intercellular spaces contain air, and being in connection with each other afford a channel whereby the various gases can circulate inside the plant.

The cells near the exterior of the plant very often contain the green colour bodies, chlorophyll corpuscles, and these cells play a very important part in the nutrition of the plant.

Parenchymatous cells are frequently used for the storage of reserve material, and also for the transport of certain manufactured products to different parts of the plant.

In trees the requisite amount of support is given by the woody portion of the fibro-vascular bundles, but in succulent and herbaceous plants this wood is generally not sufficiently developed for this purpose, and prosenchymatous cells are formed in the ground tissue which have their cell-walls thickened to help in giving mechanical support to the plant. These strengthening cells are found sometimes in connection with the fibro-vascular bundles, at other times close to the epidermis. Mechanical cells in connection with the fibro-vascular bundles are especially developed in the group of plants known as monocotyledons (Grasses, Lilies, Sedges, Rushes . . .) (fig. 17), and form a strong sheath surrounding

and protecting the fibro-vascular bundles. The cell-wall is thickened evenly, with the exception of small pits left in the cell-wall.

Mechanical cells close to the epidermis have sometimes the cell-wall evenly thickened, sometimes it is only at the corners of the cells that the thickening is developed. Cells in this position require that their cell-walls should

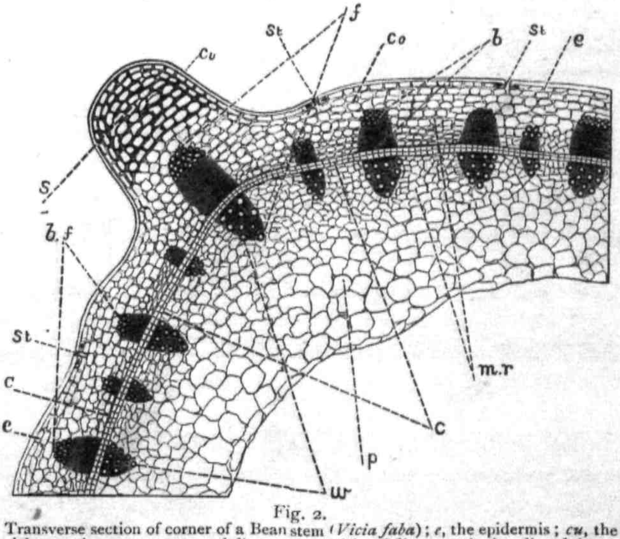


Fig. 2.

Transverse section of corner of a Bean stem (*Vicia faba*); *e*, the epidermis; *cu*, the cuticle; *co*, the cortex; *mr*, medullary ray: *p*, pith; *f*, fibrovascular bundle; *b*, bast; *bf*. bast fibres; the shaded portion between the cambium and the bast fibres represents the bast vessels and parenchyma; *c*, cambium; *w*, wood; *s*, strengthening cells at the corner; *st*, stoma.

be capable of stretching or of compression, that the plant may be bent without injury, and so the thickened cell-wall is elastic, and the thickening at the angles of the cells aids in giving additional strength to withstand pressure in any direction.

Fibro-vascular Bundles.—In fig. 2, of a transverse

section of a Bean-stem, numerous groups of cells are seen very different in appearance to the cells of the ground tissue in which they are embedded. These are the fibro-vascular bundles, and it is easily seen that they may be divided into two portions, one nearer the centre known as the wood, or zylem, which is darker by reason of the thickness of the cell-walls, and conspicuous by the larger openings of many of the vessels; and another portion known as the bast, or phlöem, immediately exterior to the wood, having an internal portion abutting on the wood with white, thin walls—the soft bast—and an external portion with hard, thick walls—the hard bast.

The fibro-vascular bundles are strands of conducting tissue traversing the whole plant. In the leaf they form a net-work known popularly as the veins, which are continuous through the leaf-stalk with those of the stem. In the stem they are also connected together, and form a net-work with large meshes, and these are again continued into the root.

Wood.—The various elements which constitute the woody portion of a fibro-vascular bundle may conveniently be classified under three heads—vessels, fibres, parenchyma. Although, in the first case, the walls of these various elements were made of cellulose, yet, when mature, the cellulose becomes converted into another substance known as lignin.

Vessels are formed from a number of cells in connection with each other, being transformed into a tube by the partition walls becoming absorbed. The diameter of the vessels is often very much larger than that of the other elements of the wood, and their walls must be specially thickened to prevent them being crushed in and the cavity of the vessel

obliterated. The simplest form of thickening is found in the primary wood, that is, the wood vessels which are first formed; these may be either spiral vessels, where the thickening is arranged in a spiral manner, or annular vessels, where the thickening occurs in rings. In the walls of the other vessels small spaces remain unthickened, often arranged in a pattern (fig. 15), so that these vessels are known as pitted or dotted ducts; or bars of thickening may be placed on the walls, and these are then known as reticulate vessels. Vessels are used for conveying water from the roots through the stem up to the leaves.

The Fibres are long cells with pointed ends which dovetail into each other, and serve to give greater strength to the structure.

The Parenchyma cells of the wood are living cells, and retain their protoplasm, and at certain seasons they may be used as receptacles in which reserve material may be stored up. The vessels and fibres lose their protoplasm, and so the parenchyma is the only living part of the wood.

It is by means of the wood that the various substances absorbed from the soil by the roots are passed to the leaves, and the soft bast forms a channel whereby those substances containing nitrogen are conveyed to parts of the plant where they are required.

Bast.—The elements of the bast, like those of the wood, may again be divided into vessels, fibres, and parenchyma.

The *Fibres* are known as hard bast, and form a protection to the soft bast (sieve tubes and parenchyma); they are formed from very long cells whose ends fit into each other in the same manner as the fibres in the wood: they form the most exterior part of the bundle.

The *Vessels* have thin walls, and are characterised by the

partition walls not being absorbed, but perforated by a number of very fine pores through which the contents of one sieve tube may pass into the next one. These perforated plates are known as sieves; they may occur on the sides of the vessels as well as at the ends, and these vessels are therefore known as sieve-tubes (fig. 16).

The *Bast Parenchyma* is thin-walled, and fits in between the sieve-tubes.

Vacuole and Cell-Sap..—The spaces in the protoplasm which are termed sap-cavities, or vacuoles, contain a watery fluid known as cell-sap. This contains various substances which are collectively known as cell contents, some of which are in solution in the cell-sap while others are present as solid bodies. The chief substances which are dissolved in the cell-sap are organic acids, sugar, colouring matters, various inorganic salts as chlorides, nitrates, and sulphates, and various compounds of nitrogen, though it rarely occurs that they are all found in one cell. Some of these are waste products, while others are about to be transformed into useful products. The cell-sap permeates the protoplasm and cell-wall.

The cell-wall and protoplasm readily allow water to pass through them to and from the cavity of the cell, but the protoplasm offers a resistance to the escape of the soluble cell contents, and it is these which, by attracting water, give rise to turgidity. If the density of the solution of cell-sap in two adjoining cells is not equal it will tend to equalise, and water will pass from one to the other. The more the soluble cell contents the greater is this force of attraction, hence, in a tissue of cells, a current will flow in the direction of greater concentration. The various organic acids are the chief factors in the cell-sap which maintain and increase the volume of the cell.

Plasmolysis.—Artificially, the turgidity of a cell may be diminished, or even destroyed, by placing it in solutions stronger than the cell-sap. Thus, for example, if a moderately thin section containing living cells be cut from a plant—a Beet-root will be found very convenient on account of its coloured cell-sap—and placed in a solution of saltpetre or common salt of about 5 per cent., this, being stronger than the cell-sap, will withdraw water from the cell, and the cell will lose its turgidity. As a consequence, the tension of the cell-walls is relaxed, and therefore the volume of the cell is diminished; the sap-cavities lose water, and the peripheral protoplasm is torn from the cell-wall, and if the surrounding solution is sufficiently strong—about 10 per cent.—it will eventually be separated from the cell-wall, and become contracted into a rounded mass.

In this condition the cell is said to be *Plasmolysed:* the cell-sap has become more concentrated, the peripheral protoplasm having retained all the soluble contents, and allowed only water to pass through it and escape. (This is well seen in the Beet-root cells by the deepened colour of the cell-sap.)

The cell is, however, not dead, but if placed in pure water the protoplasm and cell-wall will again expand and assume their healthy condition. The cause of this is exactly the same as that which brought about the Plasmolysis, namely, the concentration of the cell-sap being now greater than the surrounding water, the latter is therefore absorbed, the sap-cavities increase in volume, and the cell resumes its former turgidity.

If the protoplasm be killed, the cell-sap readily passes through the peripheral protoplasm and escapes.

It must not, however, be supposed that only water is

capable of passing from cell to cell; various substances, such as solutions of sugar, etc., may pass from one cell to another, but their passage is regulated by the peripheral protoplasm, for many solutions are able to pass through the cell-wall which cannot pass through the peripheral protoplasm.

Cell Contents.—Various substances are found in the cell which may conveniently be classed under the head of cell contents. Of these it will be sufficient to consider the following:—

1. **Plastids**, or small bodies having substantially the same properties as protoplasm, are found embedded in it in certain cells. They are formed in the very early stages of the cell and may exist under three conditions.

(*a.*) *Chlorophyll corpuscles, or chloroplastids*, small green ovoid bodies embedded in the protoplasm of those cells which are exposed to light. They are specially formed portions of the protoplasm, each consisting of a protoplasmic frame-work, in the meshes of which the green colour is contained. Although these bodies are exceedingly small yet they are so numerous that the green colour of plants is due to their presence. Their function will be considered under the leaf.

(*b.*) *Colour bodies, or chromoplastids*, small bodies of similar nature, but red or yellow in colour. The red and yellow colour of flowers or fruits and the autumnal tints are due to these bodies; in the latter case they are formed from disintegrated chlorophyll corpuscles. (Blue and purple colours are due to colouring matters dissolved in the cell-sap.)

(*c.*) *Starch-forming corpuscles, or leucoplastids*, small white bodies which may be regarded as colourless chloro-

phyll corpuscles. They are formed in cells not exposed to light, and are concerned in the formation of starch in these parts.

2. **Reserve materials,** or substances manufactured at any time in excess of present requirements are stored up in the cells for future use. These are divided into two groups according as they are to be used to form new cell-wall, or protoplasm. The former are therefore non-nitrogenous, and the latter nitrogenous.

The principal non-nitrogenous reserve materials are—

(*a.*) *Starch.*

This occurs in many cells as small grains (fig. 3); cells of the Potato (fig. 19) and of the Pea (fig. 30) are very rich in starch grains.

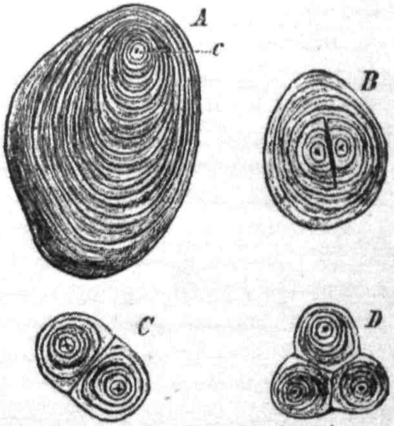


Fig. 3 (× 540.—*From Strasburger*). Starch grains from tuber of Potato. *A*, a simple grain, showing line of stratification and hilum at *c*; *C* and *D*, compound grains.

(*b.*) *Sugar* is found dissolved in the cell-sap of the Beet-root, Mangold-wurzel, etc.

(*c.*) *Inulin* occurs in the tubers of the Jerusalem artichoke (*Helianthus tuberosus*). It is always in solution, but can be precipitated by alcohol in the form of sphere-crystals.

The nitrogenous reserve materials are principally found in seeds. These are small ovoid bodies known as *aleurone grains* and may be confined to certain cells

(*wheat*, fig. 34) or contained in the same cells as the starch (*pea*, fig. 30).

3. **Waste products.**

(*a.*) *Crystals* of various forms are often found in cells (fig. 11). They are, for the most part, formed of calcium carbonate (chalk), or calcium oxalate; these crystals assume either an octagonal or prismatic shape and may be formed in cells specially devoted to this purpose. Long needle shaped crystals, pointed at each end, known as *raphides*, occur in many plants. They are found to be of service to young seedlings in preserving them from being eaten by slugs.

(*b.*) *Tannin* is found in solution in various cells, especially those which may be cast off (*i.e.*, bark). It is a waste product.

CHAPTER III.

ROOT.

If a seed be planted under favourable conditions—which will be fully considered in Chapter VII.—it germinates; that is, the young root emerges from the seed and commences to penetrate the ground, and after a short interval the stem bearing the leaves also emerges and proceeds to grow upwards.

By the term "root" we generally understand that part of a plant which grows downwards into the soil and has the main purposes of anchoring the plant and of absorbing its food-substances from the soil. Although this is generally true, we must not consider as roots all subterranean parts of a plant, nor even refuse to regard certain ærial parts as roots. In many plants the stem is always underground and similarly roots are formed which never penetrate the ground. We shall, however, consider simply those roots which penetrate the soil, and it will be necessary to examine the structure of the root before considering its functions and actions with regard to the soil.

Structure.—In beginning a study of the root, its structure is best examined by means of cross sections, which should be cut accurately transverse to its axis, and so thin that they are transparent and the walls of the various cells can be seen under the microscope. We will now first consider such a transverse section of a young root not far

from its growing point. Such a section is represented in fig. 4.

The Root, it is noticed, is circular in outline, and made

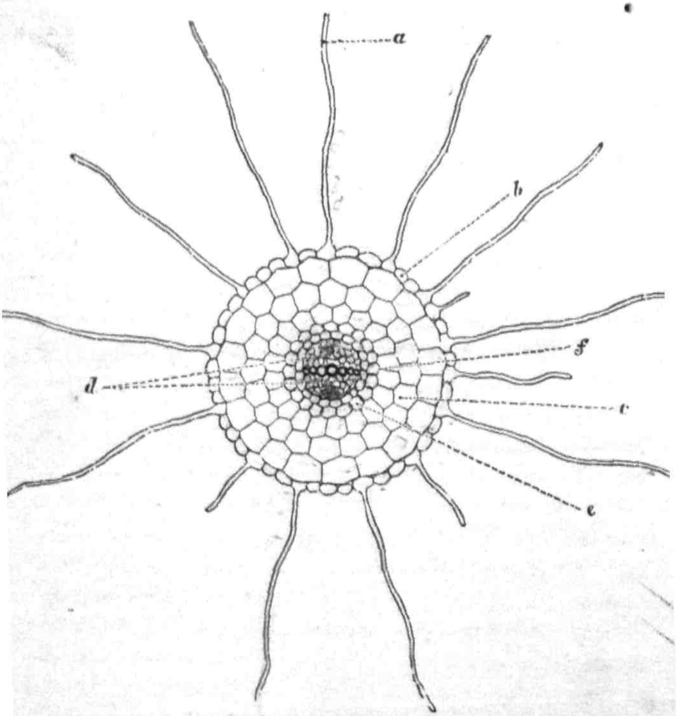


Fig. 4 (*after Vines*).

Transverse section of the root of Cress (*Lepidium sativum*): *a*, the unicellular root hairs; *b*, the piliferous layer; *c*, the ground tissue; *d*, the fibro-vascular tissue; *e*, the bundle sheath; *f*, the wood-vessels. The pericycle is the circle of cells immediately inside the bundle sheath.

up of a large number of cells, among which we very easily distinguish the three tissue systems;—in the centre the

Fibro-vascular tissue, surrounding this the Ground tissue, and on the outside a layer of cells which is described as the *Piliferous* layer. This corresponds to the epidermis of other parts of the plant, and is the layer which gives rise to the root-hairs.

The Fibro-vascular bundles are composed of two parts,—the wood and the bast. The Wood-vessels (conspicuous by their thick walls) are seen as a number of circles forming a row in the centre (fig. 4) of which the central one has the largest diameter, whilst those on each side of it gradually diminish in size. The smaller vessels at either end are the spiral vessels, and are those which are first formed, the formation of vessels proceeding inwards. Succeeding these are larger pitted or dotted ducts which in the particular case under consideration unite in the centre. Sometimes, when there are many groups of spiral vessels, the pitted ducts do not extend very far towards the centre, which is then occupied by pith cells. The Bast is seen as a group of cells situated above and below the row of wood-vessels, the more external being the bast fibres and immediately inside these the bast vessels or sieve tubes and parenchyma. The number of strands of bast always equals that of the wood, and they regularly alternate with each other at equal distances from the centre. A careful examination of the figure shows that there are two well-defined circles of cells surrounding the central fibro-vascular cylinder—the more internal of these abuts upon the spiral wood-vessels and the bast fibres, and is known as the *pericycle*. The external one is known as the *bundle sheath*. Its cell walls have often peculiar thickenings; sometimes it is the internal and radial walls which are thickened, at other times the radial walls parallel and per-

pendicular to the axis of growth have tooth-like thickenings which fit into each other. The bundle sheath is the most internal layer of the ground-tissue.

The Ground-tissue forms the great mass of the root, and extends as far as the piliferous layer; it is composed chiefly of parenchymatous cells which have intercellular spaces between them—often very large.

The Piliferous layer surrounds the ground-tissue and forms the most external layer of cells; many of its cells grow out into long tubes known as *root-hairs*.

The structure of all roots in their young condition is essentially the same, though there are great variations in detail, and they may be greatly modified as growth proceeds. In the example we have described, the wood and bast at first consist each of only two strands, but comparatively speaking few roots have so low a number as this, and in many instances the number of strands is very large. The pericycle too in some roots consists of more than one layer of cells.

Soil.—Part of the food which a plant requires is obtained from the soil in which its roots grow, and part from the air which surrounds its stem and leaves. Before considering the manner in which the food substances are obtained from the soil, it will first be necessary to discuss its character and composition.

Soil, as we know, is not a solid mass but is made up of infinitely small particles, and these being of very varying sizes and of irregular shapes do not fit closely together, but have numerous spaces between them, which are occupied by water or air. In a perfectly dry soil, these cavities contain only air, and the earth is then capable of absorbing a large amount of moisture in the same manner as a sponge.

Suppose we take some dry earth in a flower-pot and water it, we find that a certain amount of water is absorbed and retained by the soil, but if more water be added it drains away. In this condition each particle of soil, however minute, is surrounded by a thin film of water, but the larger cavities between the various particles are not filled with water, but contain air. If, however, the conditions are such that no water can drain away, the air is expelled from the soil, and it becomes completely saturated with water. Soil may therefore exist under three conditions—firstly, in a completely dry state, containing no water; secondly, when each particle is coated by a thin film of water and the spaces between many of the particles are filled with air; and thirdly, when all the air has been forced out of it and the interstices are filled with water alone.

Root-hairs.—It is by means of root-hairs that plants obtain a great deal of nourishment from the soil. The long and delicate tubes known as root-hairs are merely cells which have elongated and forced their way between the particles of soil. The root-hair differs only from an ordinary living plant cell in its greater length, having its cell wall, protoplasm, nucleus, and sap-cavities (vacuoles). Its special function is to absorb the thin film of water surrounding the particles of soil into its own interior, and with this film of water to absorb also any substances which may be dissolved in it. In order that the protoplasm may carry on this function, it must, as we have seen, be supplied with oxygen. We thus understand how it is that too much water in the soil is injurious to vegetable life. Heavy rains and bad drainage prevent the excess of water escaping from the soil, expel the air from it, and the root-hairs are

therefore deprived of oxygen; their protoplasm becomes dormant and cannot perform its function of absorbing water, and after a time it dies unless more favourable conditions are restored. Again, too little water in the soil deprives the root-hairs of their turgidity and similarly under these circumstances their protoplasm is devitalized and cannot perform its function.

Fig. 5 (*after Sachs*). End of a root-hair of Wheat (*Triticum vulgare*), with particles of soil closely adhering to it.

The root-hairs in forcing a way through the soil become very closely attached and adhere to the particles of soil, and in this state absorb the film of water surrounding and adhering to them (fig. 5). This water is passed from the root-hair to the cell of the ground-tissue next to it, and from this cell to the one next inside it, and so on until it arrives at the wood-vessels, and thus all the water collected by the root-hairs is forced along these vessels to the base of the stem. So great is the activity of the root-hairs that they force the water up the stem and cause the phenomenon of *Root-pressure*.

Root-pressure can be very easily demonstrated (fig. 6).

A small healthy stem, such as that of a Bean or Sunflower, is cut off near the ground and replaced by a glass tube (*st*) fastened to the stump, so that no leakage can occur. This is readily effected by means of a piece of india-rubber tubing (*k*). After a short time the water from the roots rises slowly in the glass-tube, sometimes

to a considerable height. To avoid the action of negative pressure (page 55) the stem should be severed under water.

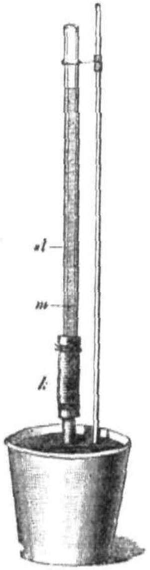


Fig. 6 (*after Detmer*).

Apparatus for demonstrating root-pressure. *k*, piece of india-rubber tubing; *st*, glass tube.

By a suitable arrangement of the apparatus, the amount of water collected by the roots may be measured, and some idea of this amount may be gathered from the fact that a large Sunflower has been found to exude nearly two pints of water in thirteen days, the exudation being very copious during the first few days and afterwards gradually diminishing.

The exudation of water from cut woody stems (*Bleeding*) which occurs so frequently in spring, is caused by the "sap" being forced upwards from the roots. This is not confined to trees and shrubs, and may often be observed in herbaceous plants.

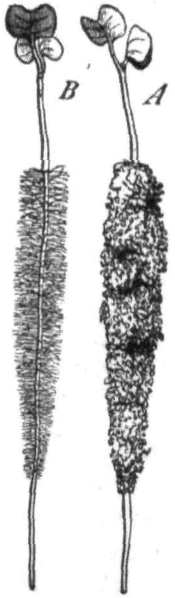


Fig. 7 (*after Sachs.*,

Seedlings of *Sinapis alba* (white mustard). *A*, after removal from the soil, with its particles still adhering to the root-hairs; *B*, after their removal by washing.

So close is the contact between a root-hair and the soil, that when a plant is pulled up (provided that the root-hairs are not broken off) some soil is pulled up with it. This is well shown in fig. 7, in which *A* is a seedling of *White*

Mustard grown in fine sand, and pulled up with the sand adhering to it by means of the root-hairs; *B* represents the same plant when the sand has been carefully removed by washing in water. It is seen in this young condition that, with the exception of the end of the root, the root-hairs cover the whole surface, and are exceedingly numerous. If, however, an older root is carefully pulled up and examined, it is then seen that the root-hairs are not present over the entire surface of the root, but that only a small zone a little removed from the various growing points is covered with root-hairs. The older parts of the root are seen to be devoid of hairs (fig. 8) as well as the growing points. Actual observation shows that the distance between the root-hairs and the tip of the root remains nearly always the same in roots of the same plant, and that as the root grows in length, new root-hairs are continually being produced just in front of those already commencing to develop, and these in their turn are gradually removed further and further from the apex.

The growth in length of the root-hair is limited, and consequently when all the food substances within its reach have been absorbed, its function of feeding the plant comes to an end, its protoplasm is withdrawn into the root, and it dies. The existence of a root-hair is therefore transitory, and this explains why the older parts of the root are devoid of hairs.

Growth in length.—We have already seen that each cell has three stages of life, and that during the second of these it grows until it has attained its mature size. It is by the simultaneous growth of a number of cells in this condition, that growth in length takes place.

In order to determine the particular region where elonga-

Fig. 8 (*after Sachs*).

Seedling of Wheat about a month old. *S*, the grain; *b*, the first leaf; *W*, extremities of roots upon which the root-hairs are not yet **developed**; *e*, older portions of root where the root-hairs have perished; *e'*, younger portions with root-hairs and soil attached to them.

tion in the root occurs, a very simple experiment may be made. If a young root be marked with lines (say of Indian

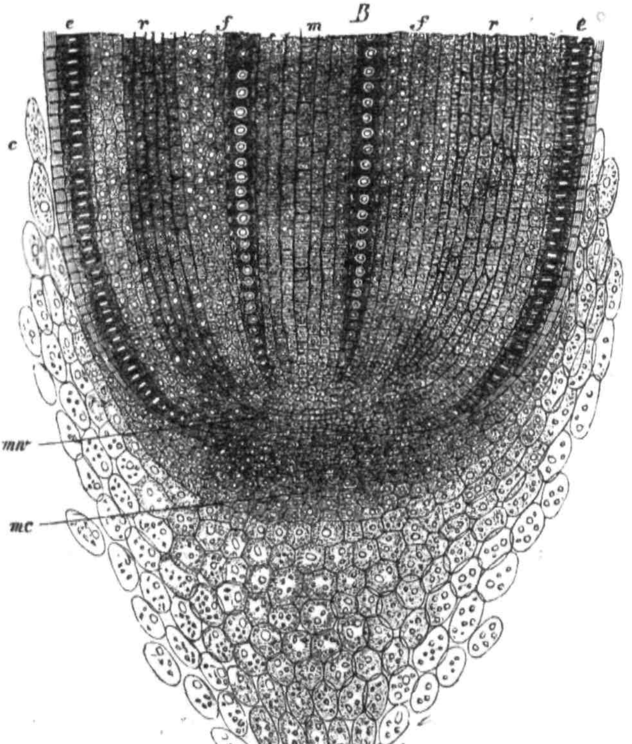


Fig 9 (*from Frank, after Sachs*).

Median longitudinal section through the apex of a root of *Zea mais* (Indian corn). *mw*, cell dividing to form the cells of the root; *mc*, cells dividing to form root cap; *c*, older cells of the root cap about to be discarded; *e*, *r*, *f*, *m*, the cells which will respectively form the *piliferous* layer, the *ground tissue*, the *fibro-vascular tissue*, and the *pith*.

ink) one-eighth of an inch apart and left for a short time to grow, in a few days it will become apparent where the increase in length is taking place, because at that point the marks will have become further apart, indicating the amount of growth. By observing a root marked in this manner, it will be seen that growth in length takes place in a very limited zone. At the tip no increase in length takes place, for here new cells are continually being formed; but at a little distance further from the tip growth proceeds very vigorously, and a little further removed from this again, growth in length altogether ceases.

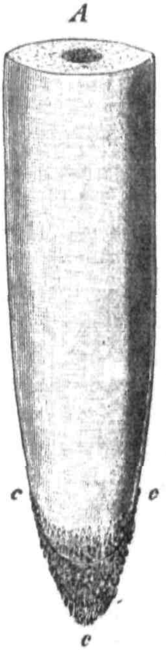


Fig. 10 (*after Frank*). Apex of root of *Zea mais* (Indian corn), showing the root-cap, *c c c*.

Growth in length then takes place very near the apex. To make this more clear a thin longitudinal section through the actual apex of a root (fig. 9) should be examined. The cells which will form the piliferous layer (fig. 9, *e*), ground-tissue (*r*), and fibro-vascular tissue (*f*) are seen clearly marked out from each other, at the apex (*mw*) the cells are seen to be dividing, and tracing the cells upwards they are seen gradually to elongate (showing the zone of growth in length) until they commence to pass over into their permanent condition. At *f* on the left hand side, a wood-vessel is being formed.

The apex of the root, it will be noticed, is covered by a conical mass of cells closely packed together at the centre, but becoming more separated at the edge; they form a structure known as the *Root-cap* (figs. 9 and 10 *c*), which

originates from a group of dividing cells (fig. 9 *mc*) immediately covering the apex of the root. These cells by their continued division form the root-cap to protect the apex of the root as it is forced through the soil. The root-cap is continually being renewed, by the dividing cells forming new ones to replace those which are destroyed or worn away in its passage through the soil.

Circumnutation.—The root has been shown by Darwin to possess the power of "Circumnutation," that is to say, the extreme end continually endeavours to move in a small circle, and is thus able to find the path of least resistance. The tip of a root never grows in a perfectly straight line, but it continually moves first to one side and then to the other, and by adopting this device the root selects the softer and more moist places in the soil, avoids the stones, and is enabled more easily to effect an entrance into very hard soils.

Geotropism.—The root, which first emerges from the seed, grows vertically downwards towards the centre of the earth, and it is a point of considerable interest to investigate the causes by which the root is guided in this direction.

A seed when planted is acted on by two forces, one the attraction to the centre of the earth known as "Gravity," and the other the centrifugal force caused by the rotation of the earth and acting directly away from the centre. The former is much greater than the latter. The young root therefore is acted on by these two forces and its direction of growth coincides with that of the prevailing force. It would seem then that this force determines the direction of the root, and in order to prove whether this is the case or not, Andrew Knight devised an experiment which has since become familiar under the name of "Knight's Wheel."

This is merely a small wheel made to rotate in the horizontal plane with a number of seeds attached to its circumference. If these seeds are kept for a few days under the conditions favourable to germination (see Chapter VII.), which may generally be done by covering them with a bell-jar, it will be found that all the roots on germination instead of growing vertically downwards commence to grow in a direction nearly horizontal, turning away from the centre of the wheel.

In order to understand this we must consider briefly the forces which act on the seeds revolving on a Knight's Wheel. These are again two, namely gravity acting vertically downwards, and the centrifugal force caused by the rotation of the wheel acting horizontally away from its centre. The resultant of these forces plainly acts in a direction inclined to the horizontal, and away from the centre of the wheel. As it is in this direction that the roots of these seeds grow, it is clearly demonstrated that the direction which the roots assume is determined by the resultant of the forces acting upon them.

The root is therefore said to be *irritable*, and by this is meant that it responds to external conditions.

If the seeds which are placed on Knight's Wheel have already germinated, a very pretty experiment can be made by fixing the seedlings with their roots pointing towards the centre of the wheel, that is in exactly the opposite direction to that in which they would naturally grow. In a few hours it will be found that the tips of the roots have turned to point in exactly the opposite direction. It is also very interesting to note that the region where this reversal takes place is just behind the tip or where the cells have not yet become permanent, showing that

only growing cells are able to respond to the stimulus of irritation.

Root Branching.—The root which emerges from the seed and grows straight down is known as the *tap* or *primary* root. Numerous branches are borne upon it, which again in their turn branch and re-branch until a very complex root system is developed. These are termed *lateral* or *secondary* roots, and are developed in obedience to two main laws. According to the first law, the younger roots are developed nearer the apex than those which are older, and so between any two roots another one younger than either is never produced. This arrangement is known as *acropetal.* The second law determines the particular cells from which they are produced. In considering the structure of the root, we have seen that the primary wood-vessels touch a zone of cells known as the pericycle. It is from the pericycle cells, which are opposite to the primary wood, that the lateral roots are developed. These cells divide to form a root-cap and the cells which, when mature, will become the three tissue systems. The young root then commences to bore its way through the bundle sheath, cortex and piliferous layer of its parent root, and finally emerges as a lateral root. Roots formed in this manner are said to be *endogenous.*

From the manner of their origin it follows that the lateral roots are arranged one above the other. The Cress root (fig. 4) can have only two rows of lateral roots, since it has only two groups of primary wood or protoxylem. The Broad-bean has four groups of protoxylem, and consequently the lateral roots are arranged in four rows.

The lateral roots do not grow straight down, but are

always inclined to the vertical, spreading out in all directions.

Increase in thickness.—In many roots the diameter is the same throughout their entire length excepting only the growing point; others are conical, gradually diminishing in diameter towards the growing point, exaggerated examples being found in carrot, parsnip, &c. The former kind have no power of increasing their diameter after it has once been attained; while in the latter a special zone of cells remains capable of division and the diameter of the root increases. This zone of dividing cells is called the *cambium:* it is formed by the division of the cells between the primary wood and bast, and the power of division proceeds on either side from these groups until a ring of dividing cells is formed, which passes on the outside of the primary wood and on the inside of the bast. The cambium thus forms a sinuous line in transverse section. Each of the cells of the cambium on division forms two cells. One of these, after growing to the original size, again divides; while the other becomes, according to its position in the root, an element of wood, bast, or parenchyma. The bast formed by the cambium is placed immediately inside the primary bast; while the secondary wood is not placed in connection with the primary wood but internal to the bast, so that the cambium cells internal to the bast form both wood and bast, the wood on their internal and bast on their external surface. Outside the primary wood parenchyma is formed. The cambium, which, when first differentiated, is a sinuous line, soon becomes circular, and thus by the activity of the cambium the diameter of the vascular cylinder increases.

The cells of the piliferous layer and ground-tissue in the root have not the power of dividing, and are therefore destroyed by this increase of the vascular cylinder; but in order to replace them the cells of the pericycle divide and form a dividing ring of cells, which form parenchymatous cells on both outside and inside, those on the outside becoming bark.

Various Functions.—Hitherto we have considered only one of the functions of the root, namely the manner in which it absorbs food from the soil, but in addition to this, the roots are the great anchors which hold plants firmly in their places, and enable them to resist the very considerable force of the wind. They may also serve as a storehouse of reserve material.

It is by the roots penetrating the ground and branching in all directions that plants are able to maintain their stems in an upright position. In plants whose height is not more than a few feet, little modification in the root is required for this purpose, but in tall trees which are exposed to high winds and are consequently liable to be blown down, the roots form large buttresses with the stem which support it on all sides. Good examples of these "Buttress-roots" are seen at the bases of such trees as the Oak, Ash, Beech, etc.

Storage of Reserve Material.—The root in many cases forms an excellent repository for the various reserve materials which are manufactured by plants for use on a future occasion. This is especially the case among herbaceous biennial, or perennial plants, which live in countries where either warm and cold, or else wet and dry seasons alternate with each other, and whose stem dies down during the period unfavourable to growth. In these

plants the leaves manufacture, during the period advantageous to plant life, more material than is required for immediate use. This excess of material is in many instances stored up in the roots, and forms the reserve fund from which stem and leaves are constructed in the next spring. An obvious advantage is gained by using the root as the storehouse, since it is hidden in the ground and cannot in hard winters be dug up by animals at the time when food is scarcest.

The root being in so many cases the plant's storehouse, contains a large amount of material which is of great value as food: this explains why roots have been cultivated for this purpose from the earliest times, and why so much trouble has been expended on their perfection. The characteristics of an edible root, or of any portion of a plant which is eatable, are a large amount of thin-walled nutritive tissue and a small proportion of thick-walled tissue. The latter—wood-vessels and mechanical cells—is necessary to the life of the plant, and cannot be entirely dispensed with, but the former may be very largely increased by cultivation. The art of cultivation, then, is to produce the maximum amount of thin-walled tissue and the minimum of thick-walled tissue. This is well exemplified in the Carrot and Parsnip, &c. Wild Carrots and Parsnips are common in many parts of this country, and an examination of their roots shows that they are very much smaller than our garden varieties, and are made up of cells with thick and very hard cell-walls. The change from this condition to that of an ordinary well-grown Carrot or Parsnip, which is nearly entirely composed of thin-walled tissue, has been brought about gradually by cultivation through many years.

CHAPTER IV.

THE LEAF.

The leaf of a plant is an object with which everyone is familiar, and yet to give a good definition of a leaf is difficult.

In treating of the leaf we may consider it from two points of view—first, that of its form; and second, that of its function. According to the first idea, a leaf is a flattened expansion differing from the stem on which it is borne, its shape being directly adapted to secure the greatest amount of light and air; according to the second idea, it may be described as an organ of manufacture and assimilation.

Generally a leaf has three separate parts, the *blade*, the *stalk*, and the *sheath*.

The **Stalk** or petiole supports the blade, and maintains it in the most advantageous position, and at its lower extremity it widens out in many cases to form the sheath. This is merely an expansion of the stalk clasping the stem, and is often produced into foliar expansions known as *stipules*.

The **Blade**, as the most important part of the leaf, should now be considered, and its structure examined. This is best done by taking thin sections cut perpendicular to its plane. Such a section is represented in fig. 11, in which the leaf is seen to be built up of the three tissues, epidermis, ground-tissue, and fibro-vascular tissue.

The Epidermis consists of a single layer of cells which covers the entire leaf, and so is found as the exterior layer on both upper and lower surfaces. The cells of the epidermis fit very closely together, in section they are rectangular (fig. 11), but in surface view (fig. 12) their shape, though very irregular, is in accordance with the general outline of the leaf, for example in the leaves of the Grasses, they are much longer than broad (fig. 12, *lower*

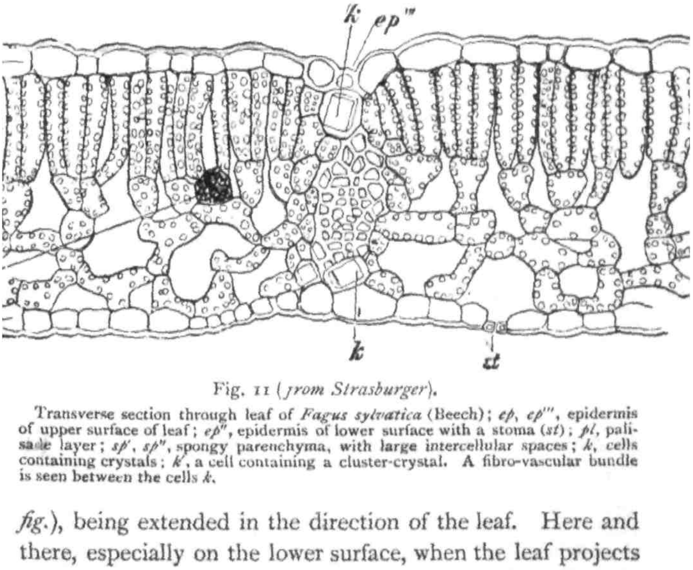


Fig. 11 (*from Strasburger*).

Transverse section through leaf of *Fagus sylvatica* (Beech); *ep*, *ep'''*, epidermis of upper surface of leaf; *ep''*, epidermis of lower surface with a stoma (*st*); *pl*, palisade layer; *sp'*, *sp''*, spongy parenchyma, with large intercellular spaces; *k*, cells containing crystals; *k'*, a cell containing a cluster-crystal. A fibro-vascular bundle is seen between the cells *k*.

fig.), being extended in the direction of the leaf. Here and there, especially on the lower surface, when the leaf projects horizontally, are small openings guarded by specially constructed cells known as stoma (fig. 11, *st*). Many of the cells are produced to form hairs,—these may be either unicellular or multicellular, and are often formed in connection with the stoma. The rough appearance of many

leaves (*Prickly comfrey*), and the velvetyness of others, is due to their presence. Comparatively speaking, few leaves are devoid of hairs.

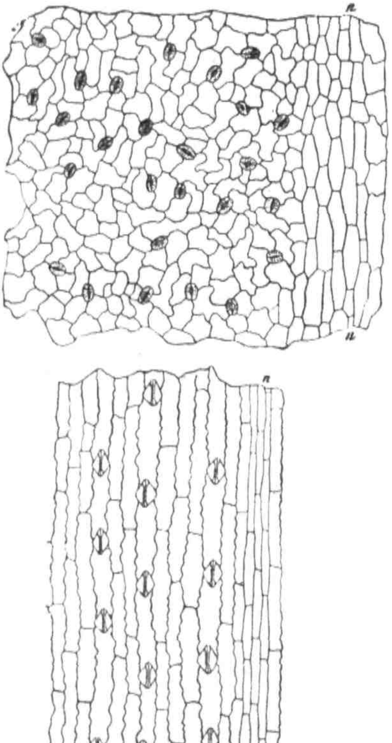


Fig. 12 (*after Frank and Tshirsch*).

Distribution of stoma on the leaves of *Beta vulgaris* (Beet), upper figure, and *Avena sativa* (Oat), lower figure. In the latter the stoma are arranged in parallel rows. *n—n*, epidermal cells covering the fibro-vascular bundles in which stoma are not developed.

The epidermal cells contain protoplasm but have no chlorophyll (page 24), except in the guard cells of the stoma; the outermost wall of the epidermal cells is often very much thickened, and the very extreme layer chemically changed into a substance known as *cutin*, so that the entire leaf is enclosed in an envelope known as the *cuticle*. The cuticle extends over the hairs and into the openings of the stoma.

The Ground-tissue of the leaf, often called the *mesophyll*, is composed

of parenchymatous cells, and is divided into two distinct layers of cells, forming two tissues, the *palisade tissue* and the *spongy parenchyma* (fig. 11). Those cells in contact with the upper surface are in shape longer than broad, they fit very closely together and have their long axes perpendicular to the upper epidermis of the leaf, from their general appearance, having their longer axes parallel to each other and in close contact, the name "palisade" has been given to them. These cells contain a large number of chlorophyll corpuscles,—some of them contain crystals, some may be formed into glands containing various oils, and some become very large, branched and thick-walled, and thus serve as mechanical supports.

Quite different in appearance are the cells between the palisade and the lower epidermis; they are characterised by their irregular shape, and by the large intercellular spaces between them, and are therefore known as the "spongy" tissue of the leaf. The intercellular spaces are in connection with each other throughout the leaf, and are especially large where they are bounded by the epidermal cells. These larger spaces form air-chambers which communicate with the outer air by means of the stoma and thus allow the interchange of various gases in the intercellular spaces with those of the atmosphere. This can easily be demonstrated by placing the blade of a leaf in the mouth and the cut end of its stalk under water,—upon blowing, bubbles of air will be seen to emerge from the end of the stalk.

The Fibro-vascular bundles are situated about the middle of the leaf, between the palisade and spongy tissues. Each bundle consists of wood and bast, with the wood nearer the upper surface.

The wood is composed of spiral or annular *tracheides*, these are wood cells which differ from the vessels in having the partition walls perforated but not entirely absorbed. The elements which compose the bast are similar to those which compose the bast of either stem or root.

The ground-tissue cells which immediately surround the bundles are devoid of chlorophyll, and are known as the bundle sheath; these cells play an important part, as the channel through which the non-nitrogenous substances are conveyed away from the leaf.

Venation.—The fibro-vascular bundles of a leaf branch and join with each other forming a network which is popularly known as the Veins (fig. 13).

The forms of venation may conveniently be divided into two groups, the parallel venation and the reticulate or net venation. In the latter, which is the commoner type for the plants of this country, a prominent fibro-vascular bundle, known as the mid-rib, enters the leaf from the stalk dividing the leaf into two halves. From this numerous lateral branches arise and these again branch and rebranch, and finally anastomose, to form a kind of net. The meshes of this net are very small and into these again branches of the bundles extend and end blindly. Sometimes more than one bundle enters from the leaf-stalk, but the veins are in communication with each other in the same manner.

In leaves like the Grasses, many bundles very close together enter the leaf and continue parallel to each other to its extremity, with here and there a fine bundle running across the leaf, connecting neighbouring bundles. Always therefore the blade of a leaf is divided into very small areas by the fibro-vascular bundles. Very good illustrations of the branching of the fibro-vascular bundles can be

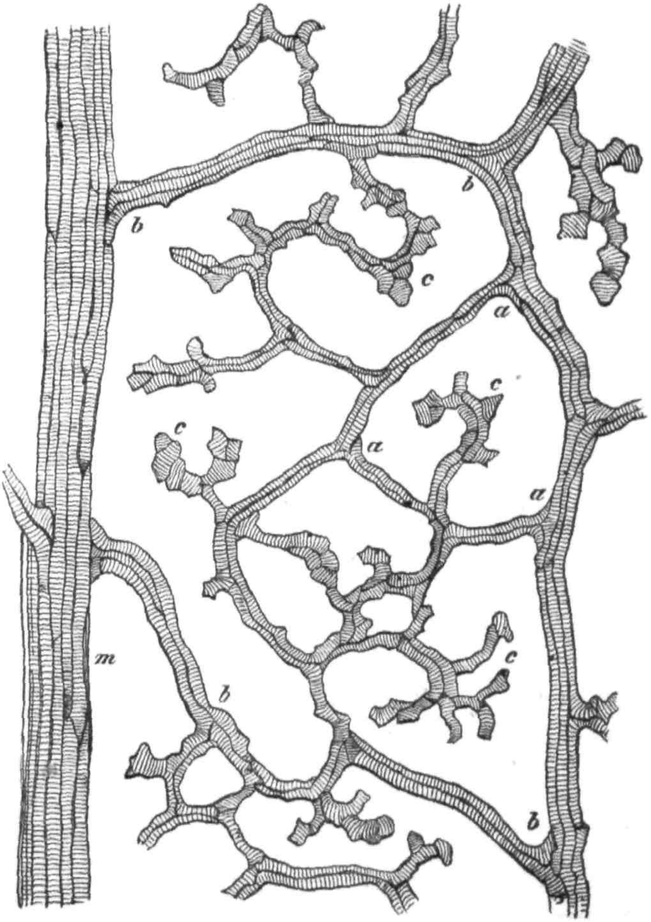


Fig. 13 (*from Sachs*).

Portion of leaf of *Anthyllis vulneraria* (Kidney Vetch or Ladies' Fingers), from which all the tissues have been removed, to show the network of the fibro-vascular bundles. *m*, mid-rib; *b*, *b*, secondary veins radiating from it; *a a a*, a closed mesh; *c*, endings of finest veins.

made by preparing leaf-skeletons, in which process the cells of the leaf whose walls are thin and made of cellulose are disorganised by soaking in water or by boiling in weak solutions of potash or soda, while the woody portion of the fibro-vascular bundles, being lignified, remains uninjured and can be easily separated, showing how each minute area of a leaf is supplied by a fibro-vascular bundle.

Stoma.—In order to connect the intercellular spaces of the leaf with the outside air, minute passages guarded by special cells are formed in the epidermis. These passages with their guard cells have previously been described and are known as Stoma, but their function in the leaf is so important that special attention must be paid to their structure and function.

The stoma are developed either directly from an epidermai cell, or, if the mature size of the epidermal cell is too large, from a portion specially cut off from it.

The cell about to form the stoma divides into two similar halves (the guard-cells), and soon assumes the form of an elliptical disc, while the division wall thickens and splits longitudinally in the centre, so that a narrow slit is formed in the thickness of the cell-wall, extending about half its length, and thus there is a narrow channel between the guard-cells opening on the inside into the intercellular spaces of the leaf, and on the outside into the air.

In transverse section (fig. 14) the walls of the guard-cells are seen to be thickened on the external and internal surfaces, the thickening extending over the walls bounding the slit, but gradually diminishing towards its central line, while the opposite wall, separating the guard-cell and its neighbouring epidermal cell, is only slightly thickened. Seen in this view the cavity of the cell, roughly speaking, is triangular.

Stoma Mechanics.—A cell, we have seen, when turgid has its cell-walls stretched and these being elastic the volume of the cell is increased. A thin cell-wall is stretched more easily than a thick one, and if a cell has some portions of its walls thinner than others, the thinner portions will naturally yield more readily to any difference in the turgidity of the cell. Now we have seen that the guard-cells of a stoma are united together at their extremities, and their walls strongly thickened around the slit, and that

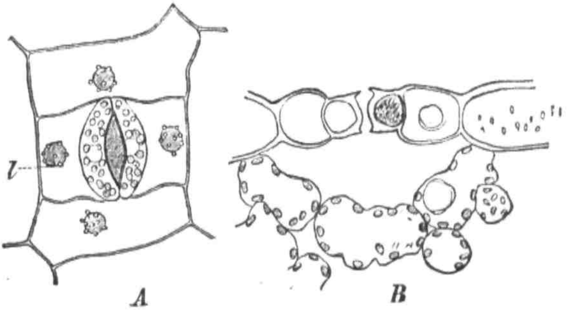


Fig. 14 (× 240. *From Strasburger*).

Epidermis from lower surface of leaf of *Tradescantia virginica* (Spider-wort). *A*, a stoma seen from surface; *B*, in transverse section with large air-chamber beneath it.

it is only the middle line of the slit and the walls opposite to it which remain almost unthickened. The variations of pressure in these cells caused by difference of turgidity will therefore affect the cell-wall at these points. Thus if the turgidity is increased they cannot increase in length since their extremities are connected together, and because of the thickening around the upper and lower edges of the slit, and the volume of the guard-cell can only be increased by the thin wall between it and the epidermal cells bulging

out, consequently the very thin portions of the walls in the slit will separate from each other, and the slit will open. Conversely, as the turgidity of the guard-cells diminishes, the aperture closes.

When therefore the guard-cells are turgescent, and this will happen when the air contains moisture and a copious supply of water is passing from the roots to the leaves, the stoma opens, but on the other hand when the air is dry and the available supplies of water from the roots are insufficient, the stoma closes. In this way the guard-cells of the stoma can approach and separate from each other, forming a beautiful piece of mechanism by means of which they regulate the interchange of gases and check excessive evaporation from the leaves, thus enabling the plant to some extent to resist adverse external conditions.

Although the stoma are usually situated on the under side of the leaf, yet they may occur on the upper side also. Their distribution on the leaf varies greatly with the habit of the plant; thus in leaves which are placed horizontally the stoma will be found much more abundantly on the lower surface, but in leaves which assume a vertical position, and therefore have both surfaces equally exposed, the stoma will be found nearly equally distributed on both surfaces. If again the leaf floats on water like that of a Water-lily, the stoma will be confined entirely to the upper surface.

The number of stoma on a leaf is almost incredible,—as many as 11,000,000 are said to exist on a Cabbage leaf, and about 13,000,000 on the leaf of a Sunflower.

Transpiration.—The root by means of its countless number of root-hairs is continually absorbing water from the soil, and with this water whatever mineral substances are dissolved in it, such as sulphates, nitrates, phosphates,

&c. It is this mineral matter which is the food of the plant, and is used either directly or indirectly in building up new cells. The water absorbed by the root-hairs contains only a small proportion of mineral matter, and hence a large amount of water has to be evaporated in order that the plant may absorb the necessary amount of food. One of the offices of the leaf is to get rid of this superfluous water.

In considering the stem we shall see how the wood-vessels of the root are continuous with those of the stem, and these again with those of the leaf, and that through the wood-vessels the water absorbed by the root-hairs is passed up to the leaves, and distributed throughout the leaf by the numerous branches of the woody portion of the fibro-vascular bundles.

The superfluous water becomes vapourised in the inter-cellular spaces of spongy parenchyma and readily passes out through the stoma, while the mineral substances remain behind in the leaf. The process whereby the surplus water is evaporated from the leaf is known as *Transpiration;* this takes place from the whole surface of a plant, but especially from the leaves, and it is a process which is exceedingly important, for without it no fresh supplies of food could be absorbed from the soil.

The amount of water transpired from a plant is very considerable, but much less than would be evaporated from an equal surface of water exposed to the same conditions; the reason of this is that the protoplasm of the living cells offers a resistance to the loss of water. To find out how much this loss is, measurements of the actual amount of water transpired from a plant have repeatedly been made. Thus Stephen Hales as early as July 1724

found that a "middle sized cabbage plant" transpired on an average 1 lb. 3 oz. (*avoir.*) in twelve hours (day), "its surface being 2736 square inches or 19 square feet," and that a Sunflower three and a half feet in height transpired 1 lb. 4 oz. per twelve hours, its surface being 39 square feet. In these experiments the quantities of water transpired were found by carefully weighing the plants morning and evening for several days, care being taken to estimate the amount evaporated from the flower-pot, and to prevent evaporation from the surface of the soil by covering it with a thin lead plate cemented to the sides of the pot.

Again Dr Haberlandt found that an Indian corn plant transpired 854 cubic inches of water in 173 days.

Experiments illustrating the amount of water transpired can be easily devised. A simple one, due to Dr Pfeffer, consists in growing a plant with its roots in water in a glass jar, and measuring the amount of water which is transpired, by the sinking of the water in the jar. In this experiment it will be necessary to prevent evaporation from the surface of the water.

Transpiration is affected by many external conditions and certain of these we may briefly consider.

Temperature and *Light* both affect transpiration, which becomes more vigorous with a rise of temperature, and takes place more rapidly in light than in darkness.

The *Age* of the leaf greatly influences transpiration. When the leaf is young, before the cuticle is fully developed, transpiration is very active, taking place through the walls of the epidermal cells, but when the cuticle is developed, this is in a great measure arrested, and transpiration then takes place through the stoma.

The *Moisture* in the air naturally affects transpiration,

and experiments prove that transpiration diminishes as the air becomes more and more saturated with watery vapour, while a dry atmosphere promotes a more copious evaporation.

The *Nature of the soil* in which a plant grows exerts considerable influence upon transpiration. In a clayey soil which retains water, the plant has a constant supply to draw upon and so transpires more than would be the case in a sandy soil, from which water very easily drains away.

The quantities of soluble mineral salts such as sulphates, nitrates, phosphates, which are some of the constituents of plant food, if present in too great a quantity retard transpiration. With each of these there is an optimum percentage most favourable to its absorption by the root-hairs and hence to transpiration, but if the percentage is increased or falls below this, less water is absorbed and the transpiration therefore is less also. With acids this percentage is greater than with alkalis, but is always very small, never being more than ·5 per cent. and often much less.

Transpiration, being stimulated by both light and higher temperatures is therefore very much less during the night than the day. During the night, the activity of the roots fills the wood-vessels, sometimes to such an extent that drops of water are found exuding from the tips of the leaves; but during the day, transpiration draws upon this supply of water, and the evaporation from the leaves causes the pressure in the plant to fall below that of the atmosphere and materially assists in causing a stream of water to flow upwards to the leaves. This *negative pressure* can easily be demonstrated by bending the stem of an actively transpiring plant beneath mercury and cutting it in two so

that the cut ends are beneath the surface of the mercury. It will then be found that the mercury is driven into the cut ends of the stem by the pressure of the atmosphere, showing that this is greater than the pressure inside the plant.

Leaves are often seen to flag upon a hot day, and to recover themselves in the evening, even when no rain has fallen. The flagging is due to the leaves losing more water from transpiration than the roots can supply. The cells of the leaf therefore lose their turgidity and the leaf droops and withers. In the evening, however, transpiration diminishes, and the roots are able to supply the loss caused by transpiration and to restore turgidity to the cells.

Manufacture of Starch.—Carbon is required as one of the constituents of cell-wall and protoplasm, and a supply of this element is necessary that new cells may be formed. The whole of the carbon required by the plant is derived from the supplies of carbon existing in the air in the form of a gas known as carbonic acid.

Carbonic acid is a colourless, invisible gas formed by the union of oxygen and carbon. When any carbonaceous matter (wood, coal, &c.) is burnt its carbon unites with the oxygen of the air and forms carbonic acid, while heat and light are given out. Not only is carbonic acid formed whenever a fire burns, but it is also formed during the process of respiration of both animals and plants. Carbonic acid is being continually supplied to the air by the respiration of every living being and by the countless smoking chimneys, and if it were not constantly being removed, the amount would become too great for the existence of animal or vegetable life. But every green plant during the daylight absorbs this carbonic acid, breaks it up into its

components carbon and oxygen, fixes the carbon and liberates the oxygen. The quantity of carbonic acid in the atmosphere is at any given time small, varying between three to nine volumes of this gas in every 10,000 of air.

In describing the cell contents we noted the presence of small green bodies (fig. 1) which are known as chlorophyll corpuscles.

The importance of the chlorophyll corpuscles cannot be over-estimated, as it is in these bodies that the carbonic acid is broken up under the influence of sunlight, and the carbon used up in the manufacture of starch. The starch then is manufactured by the chlorophyll corpuscle, but the details of the process, from the disappearance of the carbonic acid to the appearance of starch (which is the first visible product), are at present unknown.

The presence of starch can easily be determined by the use of iodine, this substance having the power of turning it a deep blue colour, and it is therefore often employed as a test for starch.

A very convenient method of demonstrating that starch is made in the leaves of plants under the influence of light, is by covering over some of the leaves of a plant, for a few hours, with a box impervious to light, and then testing them for starch with some other leaves which have been exposed to the light. This is easily done by dissolving out the green colour in alcohol (spirits of wine) and immersing them in a solution of iodine. The leaf exposed will be found to turn dark blue or even black from the presence of starch, while the covered leaves will remain almost white, or turn a yellow-brown. This experiment only proves that starch is made in the leaves; in order to show that it is made in the chlorophyll corpuscles a microscope

is necessary. Sections of the covered and uncovered leaves, if treated with iodine and magnified, will show that in the former no starch is present in the cell, and that in the latter minute grains of starch may be seen in the chlorophyll corpuscles.

In trying this experiment one or two precautions are necessary; firstly, a thin leaf such as that of a Balsam or Tropæolum (*Nasturtion*) should be chosen, and the leaves should be young, for if too old or thick the difference of the colours is not so perceptible; secondly, the leaves must be covered up for a sufficiently long time, which is easily ensured by covering over the leaves in the evening and examining them the next morning. The leaves will be found to discolour more quickly in the alcohol, if steeped for a few moments in boiling water, which kills the protoplasm; the spirit will then saturate the leaves more readily and dissolve the green colour.

Very interesting experiments can be performed by exposing only a part of a leaf previously kept in darkness—this can be done with tinfoil or thick brown paper—and then testing for starch as before. Patterns and letters cut in the tinfoil can be accurately reproduced on a leaf in this way, care being taken not to sever the leaf from the plant, or in any way to injure it.

We have thus seen the influence of light and how indispensable it is to the manufacture of starch; it now remains to consider the details of the manufacture and to show that carbonic acid is broken up when starch is formed. This can easily be determined by exposing a plant to the light in an atmosphere containing no carbonic acid, when no starch will be formed; or by exposing one half of a leaf to an atmosphere with no carbonic acid, and the other half

to an atmosphere having this gas as one of its constituents,—then it will again be found that starch is manufactured only in the half which has a supply of carbonic acid to draw upon for the carbon which is required in the formation of starch.

By growing plants in an atmosphere containing a given amount of carbonic acid, it can be ascertained by careful measurement and analysis that all the carbon disappears from the air, and that the weight of the plant is increased by the weight of the carbon manufactured into starch, while the oxygen is set free into the air.

Heat too plays an important part in assimilation. The lowest temperature at which starch can be formed varies with different plants. Some can even assimilate at a temperature as low as 36° F., though of course feebly. The temperature most favourable is about 86° F. and at temperatures higher than this it again diminishes.

The process may be briefly summarised thus :—

If starch is heated in the air to a sufficiently high temperature it takes fire and burns, its carbon unites with the oxygen of the air, carbonic acid is formed, and the hydrogen and oxygen pass off as steam; that is, the starch disappears, carbonic acid and water are produced, with the evolution of light and heat. In the manufacture of starch this process is exactly reversed, water and carbonic acid are absorbed by the chlorophyll corpuscles, and these derive the energy necessary to break up the carbonic acid from certain rays of the sunlight.

Although carbonic acid in the air is essential to plant life, yet if present in too great a proportion it is very injurious. The optimum amount of carbonic acid is about 9-10 per cent., being greater in direct sunshine than in a

dim light; quantities above this retard the formation of starch.

Transference of manufactured products.—The various nitrogenous compounds known as proteids which are made as the preliminary step in the formation of new protoplasm, are manufactured partly from the raw material, such as the various salts absorbed by the roots.

Our knowledge as to the exact chemical process by which proteids are manufactured is still incomplete, but it appears that these substances are manufactured in the cells which contain chlorophyll, and therefore chiefly in the leaves. This is shown by a larger amount of proteids being found in the leaves than in other parts of the plant, and a correspondingly small amount of unmanufactured nitrogenous salts.

The leaves then are the seat of manufacture of both the nitrogenous and non-nitrogenous substances which are used in building up a plant, and these substances must be conveyed to other parts of a plant in order to make room for additional supplies to be made. These manufactured substances obviously travel to parts of the plant where they are required to be used in the formation of new cells, or are stored up as reserve material to be drawn upon on a future occasion.

The paths by which the nitrogenous and non-nitrogenous substances travel are always kept distinct from each other. The proteids travel in the sieve tubes, while the non-nitrogenous compounds are conveyed from cell to cell in the bundle sheath or in the parenchyma between the bundles and the lower epidermis. A pretty experiment to illustrate this may be tried by placing a thin leaved plant such as a Nasturtion (*Tropæolum*) in the dark for a night, and

in the morning discolouring and treating with iodine (see page 57), when the fibro-vascular bundles will be found picked out as black lines, showing that during the night the starch made in the previous day had been collected to the parenchyma in connection with the fibro-vascular bundles, as a preparatory step to being conveyed from the leaf. Exposure to darkness for a longer period and similar examination, will show that all the starch has been conveyed away from the leaf along these channels.

The small pores in the cell-wall by which the protoplasm of one cell is in connection with the next are far too small to admit a starch grain to pass through, the starch grains must therefore be rendered soluble, and for this purpose they are converted into a kind of sugar, and in this form the non-nitrogenous substances are readily conveyed from cell to cell; during this process, however, the sugar may temporarily be re-converted into starch.

CHAPTER V.

STEM.

The stem, generally speaking, is that part of a plant which grows upwards, bearing the leaves, affording them support, and enabling them to secure to the best advantage the necessities of light and air. As we shall see later on, it may be modified to serve other purposes in the plant economy.

Bean Stem.—As a type of a stem we will first consider that of the Field Bean (*Vicia faba*), and then proceed to consider the stems of a few other types of plants. On external examination this stem is found to be square, with a prominent ridge running down each corner. It is divided into a number of lengths by the insertion of the leaves, the points of insertion being known as nodes, and the portions of the stem between them as internodes.

A thin transverse section through an internode, cut with a sharp razor or knife, shows that the internodes are hollow; while, cutting the stem longitudinally in halves, we further learn that the central cavity extends from the root to nearly the top of the stem, gradually diminishing towards these extremities. With a little magnification (fig. 2) the epidermis, ground tissue, and fibro-vascular bundles can be clearly made out.

The *Epidermis* forms, as in the majority of cases, a layer of one cell in thickness, with the surface of the outer walls

cuticularised. Numerous stoma are present, and the stem is smooth, so that no cells are found projecting as hairs.

The *Ground tissue* may conveniently be divided into three portions—(*a*) a central portion, the *pith*, enclosing the hollow cavity, and itself enclosed by the fibro-vascular bundles; (*b*) a peripheral one, the *cortex*, enclosing the fibro-vascular bundles; and (*c*) the part which separates the individual fibro-vascular bundles, the *medullary rays*.

The cells of the pith are parenchymatous and thin-walled; they contain no protoplasm, and are therefore dead. These cells are, however, not always in this condition; near the growing point, where the first few internodes are solid, and have not grown to their full length or thickness, the pith cells are in the living state, but their power of increasing by division is limited, and hence, as the stem assumes its final thickness, numerous intercellular spaces are formed, which result in the formation of one large intercellular space, the cavity of the internode.

The cortex cells are easily divided into two groups—(*a*) thin-walled parenchyma cells (fig. 2, *co*), containing protoplasm with chlorophyll corpuscles; between these cells are numerous intercellular spaces communicating with each other, and with a much larger space beneath each stoma, resembling somewhat the spongy tissue of a leaf—(*b*) cells with their walls thickened, especially at the angles; these occur at the four corners (fig. 2, *s*), and take part in the mechanical construction of the stem. There is therefore a division of labour in the cortex cells: the thin-walled cells are assimilating cells, while those with thick walls are mechanical.

The medullary rays at first are composed of thin-walled parenchyma, but in the older internodes their walls are

thickened, forming with the wood a firm cylinder of supporting tissue.

The medullary rays which are formed in this manner extend from node to node, and are termed the primary medullary rays; but in addition to these numerous secondary rays are formed in the wood of woody stems: these differ from the primary rays in never extending to the pith, being only a few cells in height, while they resemble them in retaining protoplasm.

The *Fibro-vascular bundles* are seen isolated from each other by the medullary rays, which fill up the intervening spaces, the two forming together a continuous ring. The bundles resemble each other very closely, and confining our attention to any one of them we see the wood towards the centre of the stem and the bast immediately exterior to it. Each of these parts is built up of vessels, fibres, and parenchyma.

The *wood vessels* (fig. 2) are clearly recognised in transverse section by their larger diameters and thick walls, forming a conspicuous feature. The diameters of these vessels gradually decrease towards the internal portion of the bundle, where the spiral or annular vessels are situated (fig. 15), the vessels with larger diameters being the pitted or dotted ducts.

The *fibres* (fig. 15, *b*), though easily distinguished in longitudinal section by their pointed ends dove-tailing with each other, are hardly to be distinguished in transverse section from the parenchyma. The fibres give great strength and toughness to the stem.

The *wood parenchyma* cells have thick walls, but never lose their protoplasm, and hence are always in the living condition.

The wood as a whole assists greatly in adding strength to the stem, enabling it to bear its leaves and fruits; but

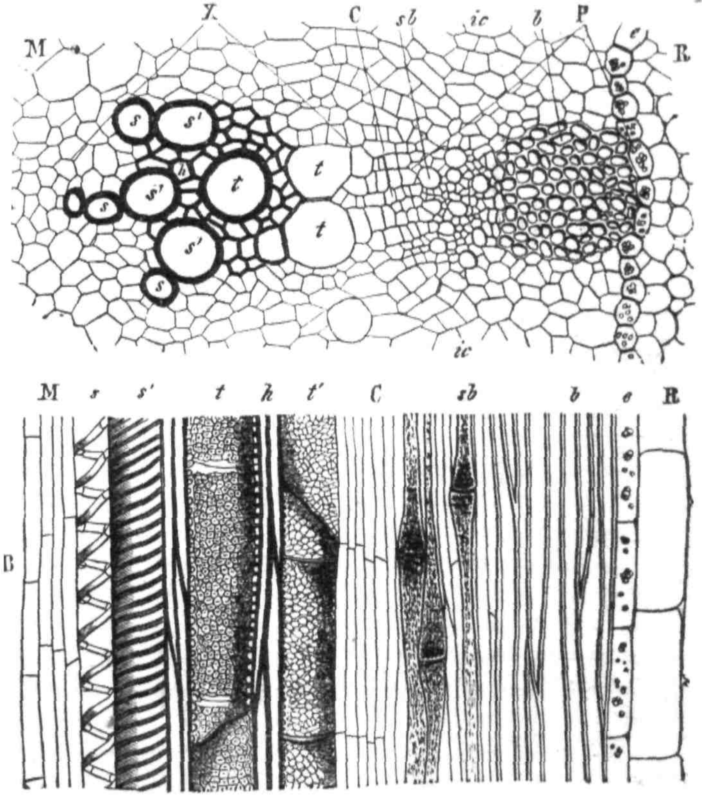


Fig. 15 (*from Prantl*).

A, transverse, *B*, longitudinal radial section of a fibro-vascular bundle of a Sunflower (*Helianthus annuus*); *M*, pith; *X*, wood; *P*, bast; *R*, cortex; *s*, small, and *s'*, large spiral vessels; *t*, pitted vessels; *t'*, a similar vessel in course of formation; *h*, wood fibres; *C*, cambium; *sb*, sieve tubes; *b*, bast fibres; *e*, bundle sheath; *is*, cambium between two neighbouring bundles.

in this, as in all herbaceous stems, strength is also derived from certain thick-walled cells of the ground tissue.

The *bast fibres*, the most exterior part of the bundle (fig. 2, *b.f.*), are thick-walled elements, very much longer than broad, with the ends drawn out to points (fig. 15, *b*) to give greater strength.

Bast vessels or Sieve tubes, unlike the corresponding elements of the wood, retain their protoplasm and cell contents. Their characteristic feature is the presence of *sieve plates*, or areas in their walls more or less circular, which are perforated with minute pores. When the sieve plates occur at the ends of these vessels, the whole area of the partition wall is perforated (fig. 16, *A*); but on the sides the pores are restricted to certain areas. The pores are the means of communication between one vessel and its neighbours. The perforations in the sieve plates vary very much in size, and are often wholly or partially closed by a substance known as *callus*. The protoplasm lies in contact with the cell wall, and is of a much more watery consistence than in ordinary cells (*B*, *pr.*) A "plug of slime" (*B*) is often found at the upper end of the sieve tube in connection with the sieve plate. The sieve tubes are rich in cell contents, in which proteids form a large proportion, and they are the channel by which these substances are conveyed from one part of the plant to another. Sieve tubes are therefore found in all parts of the plant. Being thin-walled they require support, and are always found associated with stronger elements.

Bast parenchyma, thin - walled parenchymatous cells occupy the spaces between the bast vessels.

Growth in length.—The majority of stems are capable of an unlimited growth in length; many grow upright into

the air, while others creep horizontally either on the surface or else below ground. As in the root, it is only near the apex that any extension of length can take place.

The development of leaves in the stem follows a definite law. The younger leaves are always formed nearer the apex than those which are older, each leaf arising as an

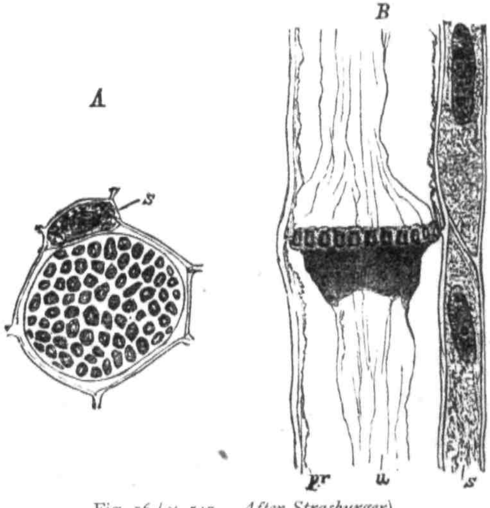


Fig. 16 (× 540. *After Strasburger*).

Sieve tubes from the stem of the Pumpkin (*Cucurbita pepo*). *A*, a sieve plate seen from above; *B*, longitudinal section of a sieve tube; *pr*, protoplasm; *u*, string of slime—the shaded portion beneath the sieve plate is the slime-plug; *s*, the companion cells.

outgrowth near to the growing point, and being succeeded by a similar outgrowth as soon as there is room on the growing point.

In exactly the same manner the youngest and smallest internodes are formed at the extreme tip of the stem. At the apex the internodes are very short, causing

the leaves to be crowded together; but as they become farther removed from the end of the stem, the distances between the nodes successively increase. The undeveloped leaves and internodes are known as *Buds*, the older leaves of which cover over and afford protection to the younger ones. Gradually, as the leaves become developed, the internodes lengthen and separate them, and the growth in length of a stem is the sum of that of all its internodes. The number of these capable of growth is not many, and differs in different plants; those which are most actively increasing in length are near the bud, so that at no great distance from the tip a maximum length of each internode is attained.

The increase in length of each internode is caused by the united growth in length of all its cells; while they are in the second stage (page 14), the length of an internode increases, but the rate of its growth gradually diminishes as its cells pass into the third stage. The life of an internode, then, passes through three stages similar to those of any of its cells.

The angle between a leaf stalk and its stem is called the *axil* of the leaf. It is in the axils of the leaves that branches are produced, and as a consequence, they follow the same law of development as leaves—that is, the younger branches are nearer the apex. A branch is, however, not produced in the axil of every leaf.

Growth in thickness.—In very young internodes the cells which are to become the three tissue systems, are clearly differentiated. Those to form the epidermis and ground tissue gradually become permanent. The cells from which the fibro-vascular bundles develop extend as strands nearly as far as the growing point, and are soon

divided into those destined to be bast, and those to be wood. The spiral vessels (fig. 15), the first elements of the wood to be formed, commence their development at the most internal portion of each bundle, and the differentiation spreads in the centrifugal direction as the other vessels, the fibres and parenchyma, are constructed. The first formation of the bast commences with the bast fibres at the external portion of the strand, and proceeds centripetally.

Two cases may now arise, either (1) as the differentiation of the wood and bast proceeds in opposite directions, these tissues meet, and all the cells become permanent, or (2) some cells between the wood and bast may not become permanent, but remain in the dividing condition, and it is these cells which are known as the *cambium*.

In the first case the bundles are said to be *closed*. Closed bundles are not uncommon, and occur in plants whose stems do not increase in thickness, such as *Grasses*, *Lilies*, *Sedges*.

In the second case, by the division of the cambium cells, elements are successively added to both wood and bast, and in this manner the bundles increase in size. The cambium cells are thin-walled, much longer than broad, and elongated in the direction of the length of the stem. They divide longitudinally by a wall parallel to the circumference of the stem, and of the two halves so formed one continues capable of growth to its original size and then divides as before, while the other becomes a permanent element of either wood or bast. From what has preceded it is clear that increase in thickness only takes place after growth in length is finished. It is in this way by the continued addition of cells, vessels, or fibres, that the woody trunks of our large trees are constructed.

Grass stem.—In many respects the stem of the Grass resembles that of the Bean, but there are certain points of difference.

The Grass stem is round and hollow, but divided into a number of chambers by transverse partitions which are developed at the nodes.

The nodes are clearly visible on the outside as ring-like thickenings, familiarly known as knots or joints. The internodes in the young stage are solid, and the cavities are formed like those in the Bean by the breaking away of the pith cells from each other.

The aerial stems of our common Grasses are terminated by the inflorescence, as the arrangement of the flowers is termed. The number of internodes taken up by the inflorescence varies according to the kind of Grass, but being nearer to the growing point than the stem-internodes, are necessarily younger than the latter; and thus, after the development of the inflorescence, no new internodes can be formed. Even when the plant is only a few inches high, the inflorescence commences to develop, and consequently the full number of internodes and leaves are formed, and the subsequent growth in height of the plant is due entirely to the elongation of the stem-internodes. The number of these in the Oat or Wheat is generally four or five, and the last one bearing the ear is generally greatly prolonged.

During a brief period all the cells of the stem-internodes take part in its elongation, but gradually they become permanent, leaving only a narrow zone (fig. 18, *v*), just above each node, in the dividing condition. It is by the division of these cells that the great part of the elongation of each stem-internode is due. In the dividing condition, the cell walls are very thin and weak, and would be unable

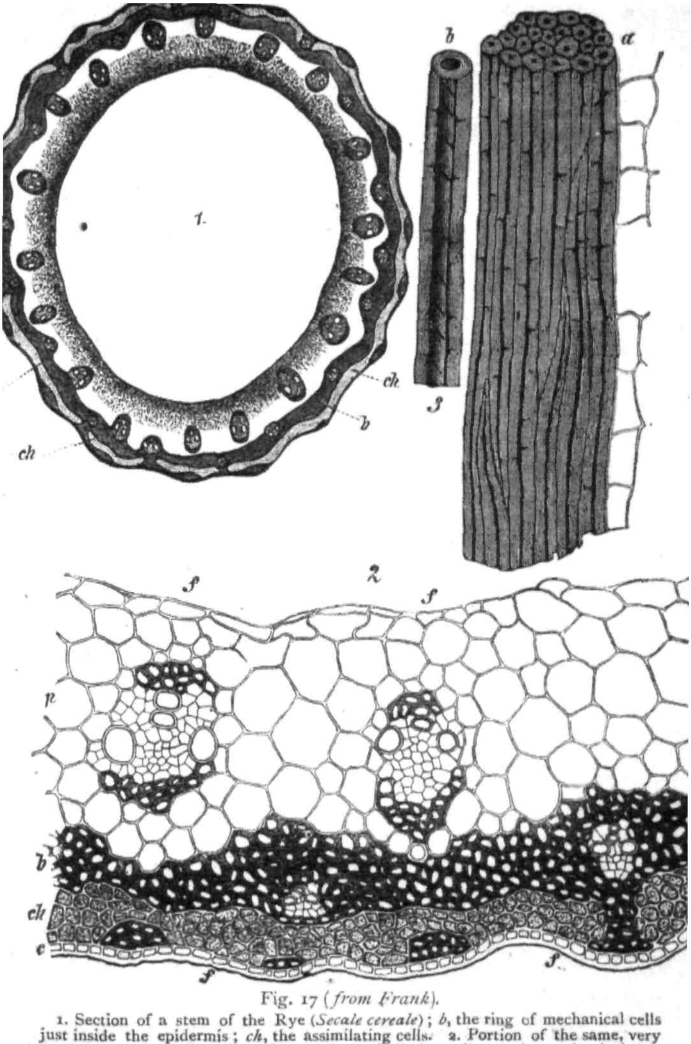


Fig. 17 (*from Frank*).

1. Section of a stem of the Rye (*Secale cereale*); *b*, the ring of mechanical cells just inside the epidermis; *ch*, the assimilating cells. 2. Portion of the same, very much enlarged; *e*, the epidermis; *ch*, the assimilating cells; *b*, the mechanical ring *in which are embedded the smaller fibro-vascular bundles*; *p*, *the large cells of the* pith in which two large fibro-vascular bundles (just beneath *f*, *f*) are embedded—the large *fibro-vascular* bundles *are strengthened on the* internal and external points. 3. Mechanical cells; *a*, in transverse and longitudinal sections, these elements are long with pointed ends dovetailing into each other; *b*, a portion of a fibre more highly magnified, with slit-like pits in the walls.

to support the stem above them, were it not that the leaf sheath clasps round the stem-internodes for nearly their

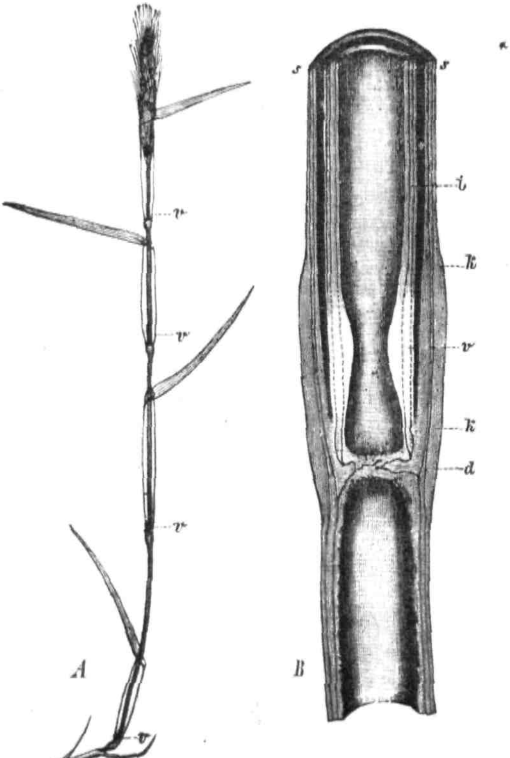


Fig. 18 (*from Frank*).

A, stem of a grass terminated by an inflorescence, showing the leaf sheaths enclosing the stem; *v*, zone of dividing cells. *B*, a portion of *A* halved longitudinally and magnified; *d*, the partition separating the hollow of two internodes; *s*, *s*, the leaf sheath swollen at *k* to form the knot; *v*, the dividing cells; *i*, internode.

whole length, and gives the requisite support to the stem.

Transverse sections of a stem of one of the cereals are seen in fig. 17. Enclosing the stem is the epidermis (*e*), and succeeding this is the cortex in which the assimilating cells (*ch*), may be clearly distinguished from the mechanical cells (*b*). The assimilating cells, which require light, are in contact with the epidermis, only here and there separated from it by a group of mechanical cells, which appear to the naked eye as white, longitudinal streaks on the green stem. The mechanical cells form a supporting cylinder (*b*).

The fibro-vascular bundles are arranged in two rings, the smaller external ones are embedded in the mechanical cells, while the larger ones are supported by mechanical cells at their most external and internal parts. The bundles have wood and bast arranged with the spiral vessels on the inside. The wood is often compared to a **V** pointing to the centre of the stem, the bast being between the arms of the **V**.

The bundles of the Grass stem differ from those of the Bean in having very few wood vessels, and hence they require the support just mentioned. They have no cambium, and when therefore one of these bundles is formed, it is closed, and has no means of increasing the number of its elements. Thus the Grass stem cannot increase its diameter, and is therefore cylindrical.

The Potato.—The Potato presents a very interesting example of a portion of a stem modified for the special purpose of storing reserve material. This is best explained by considering the life history of a Potato.

If one of the seeds from a potato fruit (often known as

potato apple or potato ball) be planted, upon germination a young plant is developed in the normal manner. The first two leaves (seed leaves) which appear above ground are smaller, and different in shape from those which succeed them (fig. 19, *A*). In the axils of these leaves and of the first few which succeed them (three in *A*) branches are produced which, instead of growing upwards, penetrate the ground (*A*). The extremities of these branches increase in diameter and so form small tubers. These tubers bear a number of scale leaves in whose axils "eyes" are formed, the eyes being small buds which will develop into shoots in the next year. The tubers, then, are stem structures, since they are borne on branches, developed in the axils of leaves, have the characteristic anatomical structure of stems, bear leaves, and have no root cap.

A section of one of these tubers shows that it consists of a large number of thin-walled cells, each containing numerous starch grains (fig. 19, *C*), surrounded by a layer of several empty cells whose walls have turned brown and which form the peel (*k*, *k*). Several of the cells just inside the peel contain small rhomboid crystaloids; these are readily soluble in water and weak salt solution, and are the nitrogenous reserve material—that is, the surplus material manufactured after the stem, leaves, and root have been formed.

If one of these tubers be planted in the next year, a stem is produced from one of the eyes which soon appears, above ground with its leaves, roots at the same time also being formed. The materials out of which these members are built, are the reserve materials stored up in the previous year. The leaves, as soon as formed, commence the

manufacture of starch and proteids, which are used in the formation of new stem, leaves, and roots. At the same

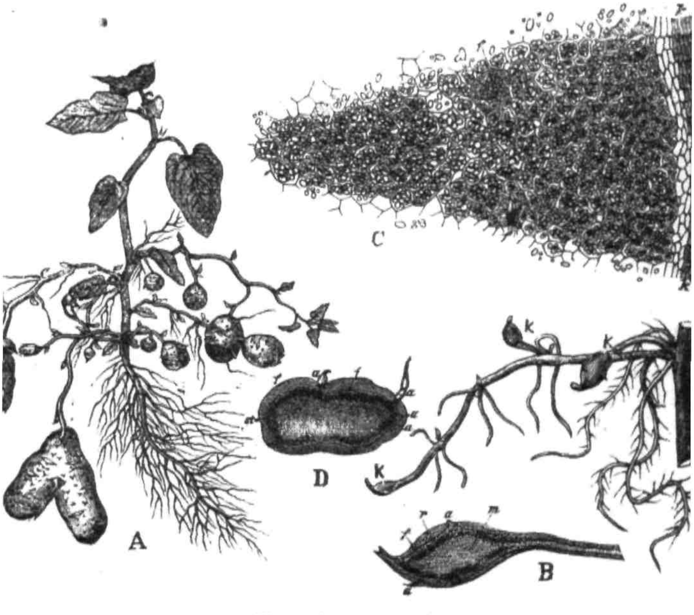


Fig. 19 (*from Frank*).

A, A seedling Potato (*Solanum tuberosum*) with small tubers forming on the subterranean branches which are seen to take their origin in the axils of the cotyledons or above them. *B*, Formation of tubers by the swelling of branches of the stem at *K*. In the lower figure a small tuber is seen in longitudinal section. *m*, the pith cells, which increase very much and constitute nearly the whole of the tuber; *r*, the cortex; *f*, the fibro-vascular bundle; *a*, scale leaves in whose axils buds (eyes) are subsequently formed. *C*, Section of a tuber composed of a large number of thin walled cells very rich in starch grains; *k*, *k*, outer corky covering; *f*, *f*, small fibro-vascular bundles. *D*, Section of a germinating tuber; *a*, *a*, *a*, *a*, various stages in the development of an eye into a stem; *f*, *f*, the course of the fibro-vascular bundle; *st*, attachment to parent plant.

time underground branches are formed, and the surplus starch and proteids are again stored up in tubers and so

on. At the end of the first year the tubers are small, but those formed each year are larger and larger until full-sized potatoes are produced.

The formation of starch in the potato tuber, and in similar parts of plants not exposed to light, is very interesting, and gives additional information as to the manufacture of this substance. The starch, we have shown, in the first instance is manufactured in the chlorophyll corpuscles, and is thence transferred to other parts of the plant, by passing from cell to cell in the form of sugar. To re-convert this sugar into starch, a similar corpuscle, the *starch-forming corpuscle*, is required. This corpuscle first enters into combination with the sugar, and then splits up into starch, and its original form. The starch first formed in this manner is placed as a small round body on one side of the starch-forming corpuscle (fig. 20, *C*, *D*), and becomes the hilum. Soon a second layer is deposited upon this, and then another, and so on until the starch grain is fully formed. The first few layers (figs. 3 and 20, *A*) are concentric with the hilum; but the starch-forming corpuscle is always situated on one side of the grain (fig. 20), and consequently, this side receives larger depositions of starch, and

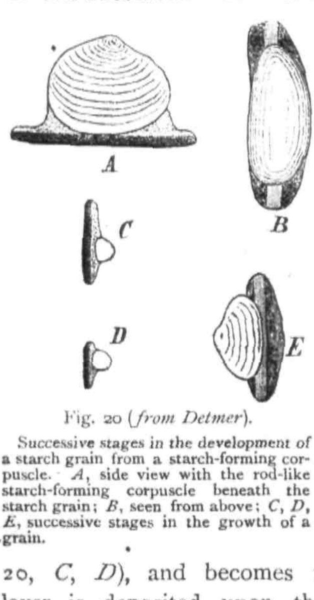


Fig. 20 (*from Detmer*).

Successive stages in the development of a starch grain from a starch-forming corpuscle. *A*, side view with the rod-like starch-forming corpuscle beneath the starch grain; *B*, seen from above; *C*, *D*, *E*, successive stages in the growth of a grain.

increases more rapidly than the side away from the starch-forming corpuscle. Starch grains are therefore excentric. A number of lines are seen upon the starch grains, and show how the successive layers are deposited upon each other; they are also evidence of the deposition of layers varying in density, and of the stratification of these grains. The growth of a starch grain is analogous with that of the cell wall; the starch-forming corpuscle—a protoplasmic body—breaks up into starch, which is deposited in successive layers on the starch grain, in the same manner as cellulose is deposited on the cell wall. The size of a starch grain is limited, from which it appears that, after a time, the starch-forming corpuscle becomes exhausted. These corpuscles are closely allied to the chlorophyll corpuscles, and when exposed to light turn green, and are then able to manufacture starch, showing that both are merely different conditions of the same body.

Various Modifications.—The buds of perennial plants (fig. 21) destined to live through the winter and expand in the following spring have two kinds of leaves, the outer are hard and scale-like, and never develop into foliage leaves, while the inner, which are to become foliage leaves, are protected by the former during the winter months.

Buds are sometimes modified to form reservoirs of reserve material. The Onion or Hyacinth *bulbs* (fig. 22) are merely buds consisting of a short conical stem which bears a number of leaves, the most external of which are brown and protective; while the next series are white, and in their cells the reserve materials are laid up. When the bulb is planted, the inner green leaves become the foliage leaves for the next season, and the apex of the short stem is produced into the aerial stem.

The *Corm* of the Crocus is also a bud, but the stem forms the reservoir, while the leaves are brown and protective except the more internal ones, which are the young foliage leaves.

Ascent of Water.—Although it has long been known that water is conveyed through the stem from root to leaf, and that the wood vessels are the channel in which it flows,

Fig. 21.

A branch with a terminal bud and lateral buds, the latter being produced in the axils of leaves which have been removed. On the exterior of the buds are scale-leaves.

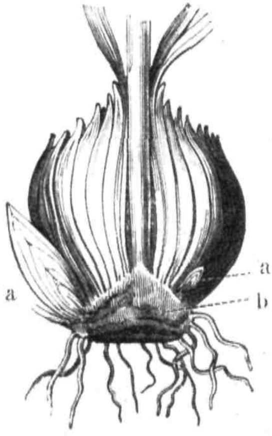


Fig. 22.

Vertical section through a bulb of an Onion (*Allium cepa*). *a*, young buds (bulbs) produced in the axils of leaves; *b*, the short conical stem.

yet an exact knowledge of the manner in which the leaves of the tallest trees are supplied with water long remained a puzzle.

To prove that the stream of water termed the transpiration current flows in the wood, it is only necessary to resort to the process of ringing, that is, to remove from a woody stem a narrow ring containing all the tissues external

to the wood—*i.e.*, bark, cortex, and bast, without injuring the wood. This can readily be done, since the cambium has thin walls, which are easily broken; it is then found that the removal of this ring makes very little difference in the health of the plant, the part above remaining quite healthy. The converse of this is equally true, if the wood is removed while the other tissues are injured as little as possible, the part above the injury commences to wither very soon. It is therefore beyond doubt that the wood is the channel in which the transpiration current flows.

The motive force by which the water is conducted is supplied by (1) the living parenchymatous cells of the medullary rays; (2) the root pressure; and (3) the transpiration.

The cells of the medullary rays suck the water from the vessels a little below them on one side, and pass it on to those a little above them on the other, in the same manner as the cells of the ground tissue of the root pass the water absorbed by the root hairs from one to another till it reaches the wood. The water therefore ascends in a spiral course. It is by the combined forces of the root pressure forcing the water up the stem, the medullary rays conducting it further along, and the evaporation from the leaves exerting a pull from the top, that water ascends to the summit of the highest trees.

Mechanics.—The stem which bears the leaves and branches should be sufficiently strong not only to support their weight, which is often considerable, but also to withstand strong gusts of wind, heavy showers of rain, or other accidents.

So fierce is the struggle for existence among plants, that the greatest economy is necessary in building a stem

of sufficient strength, yet without the addition of any unnecessary or superfluous strengthening cells. Hence it is found that the strengthening cells are placed where they can best resist strains and stresses, and the stems are constructed on the most efficient mechanical principles.

Stems may be roughly classed into hollow and solid stems. The hollow stems are characteristic of herbaceous plants, which do not reach any great height, or which do not bear large branches; but trees with large and heavy branches have solid stems.

It is a well-known mechanical principle that for the same weight of material a tube is much stronger than a solid bar, and that the most efficient form of girder to resist forces in one plane only is that of a capital H or I, the plane in which the forces to be resisted act coincides with the direction of the central part of the H, or in the length of the I. The form of this girder most commonly used is that of two strong masses (booms), connected by a more slender portion (the web). In our illustration the booms are the sides of the H, or the top and bottom of the I. The central part of the H or I is the web, which need not be solid, but one or more rods connecting the booms may be used in its construction, the only condition being that they are strong enough to resist the forces acting upon them.

In the plant we find the exact application of this principle. The booms are constructed of thick-walled cells belonging to the ground tissue, or to the bast fibres or wood of the fibro-vascular bundles; the thin-walled cells are used in the construction of the webs, such as the thin-walled parenchyma of the ground tissue, and the parenchyma and vessels of the bast. The form of girder

just described will be useful for forces in the plane of the web, but a plant stem must be capable of resisting forces in all directions, and a combination of girders is therefore necessary; and it is these considerations which determine the form of stems, some being round, some square or polygonal.

The Bean stem just described has strands of thick-walled cells at each of its corners: these are the booms, and the sides of the stem are webs. Any pair of opposite sides, therefore, are a pair of parallel girders, and resist forces in their directions; and also any corner is connected by the sides with the opposite corner, and the booms at the corners form with the sides girders to resist forces acting in the direction of the diagonals of the stem. The square stem with thickened corners then resists forces in any direction.

The principle of the girder is applied even in the arrangement of the tissues; each fibro-vascular bundle is a girder, the wood and bast fibres being the booms, and the thin-walled cells between them the web; and further, the medullary rays are webs, with the wood and bast fibres for booms.

By increasing the number of corners, and therefore of booms, the many-sided stems are constructed as a further extension of this principle; and it may be still further extended to the round stem, which consists of an indefinite number of small sides, and in this case the strengthening cells become continuous and form a cylinder of supporting tissue. A good example of this is afforded by the Grass stem (fig. 17).

CHAPTER VI.

THE FLOWER.

BOTANICALLY speaking, a flower is a specially modified shoot which bears leaves modified to serve as reproductive organs.

A few words of explanation may be offered on the term "modified." The three members of a plant, as we have seen, are constructed to perform certain definite functions, but they may also be metamorphosed and adapted to fulfil others; sometimes the main and subsidiary functions may be performed at the same time, in other cases the part is so specially altered that it is incapable of performing its original function and only performs the subsidiary one.

In this latter case the member may be so altered in form, colour, and other characteristics as to be totally unlike an unaltered member, but its position on the plant and its mode of development will always reveal from which of the three members it has been derived.

Members.—The various members of a flower being modified leaves, are developed exactly like leaves, and follow the same laws of arrangement as the foliage leaves of the same plant.

A flower usually consists of four series of members, *Calyx*, *Corolla*, *Stamen*, and *Pistil* (fig. 23).

The shoot on which the flower is borne, at first in no way differs from an ordinary shoot, and small out-

growths arise near its extremity in exactly the same manner as the outgrowths which become ordinary foliage leaves. In the development of a foliage shoot the internodes gradually lengthen and separate the leaves from each other, but in the floral shoot the internodes do not lengthen, and the floral leaves remain very close to each other. The first series of outgrowths become the sepals, and surround the growing point as a whorl.

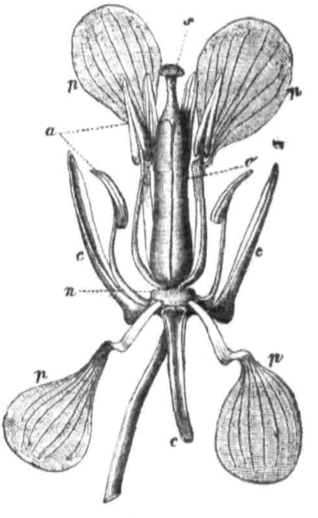


Fig. 23 (*from Frank*).

Flower of Rape (*Brassica rapa*), a crucifer, slightly magnified. *c*, *c*, *c*, the sepals, the fourth is not shown, being behind; *p*, *p*, *p*, *p*, the petals; *a*, the stamens; *o*, the ovary; *s*, the stigma; *n*, nectary.

Succeeding these the petals arise as another series of outgrowths, generally of the same number, but so arranged that each petal is developed opposite the space between the two sepals immediately below it on the floral axis.

The stamens and carpels are outgrowths similarly developed, although their number does not always correspond with that of the petals or sepals.

Gradually these outgrowths develop into the various members of the flower.

Calyx.—The *sepals*, which together form the calyx, are as a rule the least modified parts of the flower, although exceptions occur in which they undergo great modifications. Most often they are green and only altered as regards their

shape, but in some cases they may be brightly coloured. Sometimes the sepals remain quite distinct from each other (*polysepalous*), but may be united to form a cup (*gamosepalous*). Examples of the former are found in *Buttercup*, *Wallflower*, *Geranium*, and of the latter in the *White Nettle*, *Foxglove*, and *Comfrey*.

The chief function of the Calyx is to cover over and afford protection to the other members of the flower enclosed by it, hence it may fall off very soon after the flower has opened and its purpose is accomplished; but besides its main function of protection, the calyx is often used to afford support to the corolla, or to help in disseminating the seeds and fruits, instances of which will be considered further on.

Corolla.—The leaves which constitute the Corolla are known as *petals*; these are often greatly modified in shape and brilliantly coloured. The shape of the Corolla is very various—the simplest cases are plain open flowers, as in the *Buttercup*, *Strawberry*, &c.; and the more complicated ones, as *Snapdragon*, *Dead-nettle*, assume a great variety of forms. The individual petals may be quite free from each other (*polypetalous*), for example in the *Buttercup*, or may be united (*gamopetalous*) as in the *Comfrey*, *Snapdragon*, &c.

The Corolla is very often brightly coloured, and is then the showy and attractive part of the flower, its function being to attract insects in search of the honey which is secreted in various parts of the flower. The flowers which are regularly visited by insects during the day-time are generally red or blue in colour, but those specially designed to be visited by moths and other night-flying insects are usually white or pale yellow.

Stamens.—Immediately inside the Corolla are situated the stamens, which are more modified than the other members of the flower.

Generally each stamen is made up of a stalk or filament, bearing at the end a head or anther, which latter is the essential part of the stamen. A transverse section through the anther of a flower which is just about to open, shows that it contains four chambers (fig. 24), known as pollen-sacs, because in them the pollen-grains, a number of small round cells, are produced.

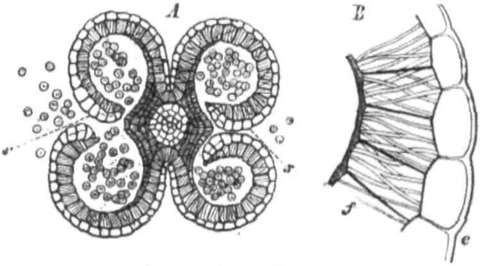


Fig. 24 (*from Frank*).

A, a transverse section of an Anther, slightly magnified, showing the two halves, each opening at *s*; some of the pollen grains are still enclosed in the anther. *B*, epidermis (*e*) and fibrous layer (*f*), highly magnified.

In the early stages of the anther, the cells which are to become the epidermis, ground tissue, and the fibro-vascular bundle can be clearly distinguished by the aid of the microscope. The most external layer of the second of these tissues gives rise by division to the cells from which the pollen grains are formed, and also to a layer of cells which with the epidermal cells forms the walls of the anther, and by the uneven thickening of its cell walls opens the chambers of the anther to allow the pollen grains to escape.

The *pollen grains*, when ripe, are small, generally spherical or ovoid cells, each having its own protoplasm, nucleus, and cell wall. The protoplasm entirely fills the cavity of the pollen-grain, and is very rich in reserve materials. Two nuclei may be detected. The cell wall consists of two layers, an inner delicate one, the *Intine*, and an outer one, the *Extine*—often firm and hard, which serves as a protective envelope, and is sometimes covered with spines or warts.

Pistil.—The last series of the flower—the pistil—is made up of one or more modified leaves—*Carpels*. These carpels, like other members of the flower, may be joined together or may remain quite separate. Each carpel may readily be divided into three parts—a lower and larger one, the *Ovary*, whose apex is prolonged into a more or less slender part, the *Style*, at the end of which is a small region often covered with sticky hairs, the *Stigma*.

A carpel is formed by the leaf folding over, so that the two free edges meet and unite to form a chamber which is largest at the ovary, and, gradually diminishing in size, is continued as a canal through the style to the stigma.

Ovule.—As outgrowths near the edge of the carpellary leaf, small bodies are borne which are known as *Ovules*. The ovule arises from the young carpellary leaves as a small conical protuberance — the *Nucellus*. Very soon after the nucellus has been formed the cells at its base by division and growth form a cup, which grows up around the nucellus and nearly encloses it : this covering to the nucellus is called an integument. Before the first integument has fully grown, a second one is formed exactly resembling it. The integuments completely envelope the nucellus with the exception of a narrow channel—the *micropyle*, which leads

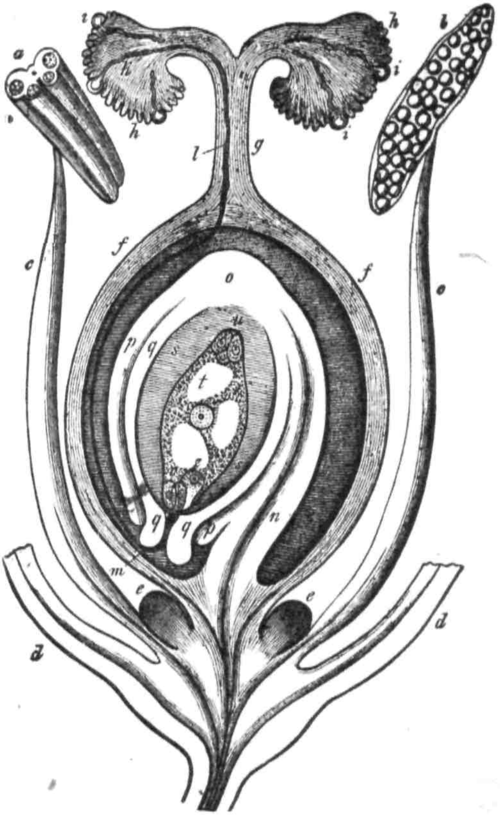


Fig. 25 (*from Sachs*).

Diagram of a very simple flower in longitudinal section. *a*, transverse section of an anther before dehiscence; *b*, anther, with pollen dehiscing longitudinally; *c*, filament; *d*, *d*, bases of sepals and petals which have been removed; *e*, nectaries; *f*, wall of ovary; *g*, style; *h*, stigma; *i*. germinating pollen grains; *k*, *l*, *m*, a pollen tube which has traversed the style and has entered the microphyle; *n*, funicle of ovule; *o*, base of ovule; *p*, the outer, and *q*, the inner integument; *s*, nucellus of ovule; *t*, cavity of embryo-sac; *u*, basal portion with antipodal cells; *v*, the co-operating cells; *z*, oosphere.

from the apex of the nucellus to the cavity of the ovary.

Generally the ovule is not formed symmetrically, but a greater growth takes place on one side than on the other, by which means it is completely turned round, so that the opening of the micropyle is brought close to the wall of the ovary.

While the formation and growth of the ovule are proceeding, a large cell—the *Embryo-sac*—is formed in the nucellus, near the micropyle. This cell in its early stages is similar to the other cells of the nucellus, and differs only in being much larger; as it continually increases in size, its nucleus divides, and of the two halves then formed one proceeds to the end of the embryo-sac, near the micropyle, while the other proceeds to the opposite end: by repeated division four nuclei are formed at each end. The next stage is the diminution of the number of the nuclei to seven, caused by one from each end travelling to the centre of the embryo-sac, where they coalesce. Of the three nuclei near the micropyle one becomes larger than the other two, and is known as the *Egg-cell* or *Oosphere.* The ovule may now be said to be fully formed.

Fertilization.—As we shall see below, the stage in the flower at which the ovule is mature is subject to great variations; but its development can proceed no further than we have just described, unless a pollen-grain has been placed on the stigma.

We traced the development of the pollen grain until it was fully formed as a single cell with two nuclei. For further development, *Pollination* must take place—that is, the pollen-grain must be placed on the stigma, it then germinates—that means, the outer cell-wall bursts, and

inner one grows out as a protuberance which soon becomes a tube growing down the style to the cavity of the ovary, in which it is directed to the micropyle of one of the ovules. Having reached a micropyle, it grows through it, eventually reaching the apex of the embryo-sac. A nucleus has in the meantime been formed at the end of the pollen-tube, and on this tube reaching the embryo-sac, its nucleus passes through the thin cell-wall of the end of the pollen-tube, and fuses with the nucleus of the oosphere. The fusion of these two nuclei constitutes *Fertilization*. The single cell so formed is now termed the oospore, and it is this cell which by repeated division eventually becomes a new plant.

Cross and Self-fertilization.—From what we have just seen, it will be noted that for the production of seed only pollen-grains and oosphere are necessary and sufficient, and hence the parts of a flower actively engaged in the process of reproduction are the stamens and carpels. These are therefore often spoken of as the essential parts of a flower, the calyx and corolla being termed the non-essential parts.

Provided the pollen-grain is placed on the stigma at the right time, fertilization may be effected, and seed produced.

It is essential that stamens and carpels should be produced, but it is not essential that both these organs should be in the same flower, or even on the same plant; and many instances occur in which the stamens and pistils are on the same plant but in different flowers—*e.g.*, Oak, Haselnut, Birch, Beech, &c.—or again, they may be borne on different plants—*e.g.*, Dog mercury, Hemp, &c.

If a stigma receives pollen from a flower of another plant, it is said to be "Cross-fertilized"; but if it is impreg-

nated by pollen from the stamens of its own flower, it is then said to be "Self-fertilized."

Mr Darwin, by a series of very careful experiments extending over eleven years, showed that "Cross-fertilization is generally beneficial and Self-fertilization is injurious." He found that plants which grew from seeds developed from self-fertilized flowers, were weaker and less vigorous than those produced from cross-fertilized flowers; and further, that although self-fertilization is generally injurious, yet many plants can be propagated for several generations by this means; but as far as he could determine, these all "profited greatly by a cross with a fresh stock."

There are several methods of preventing self-fertilization. One has already been mentioned—viz., when the stamens and pistils are on different flowers on the same plant (*monœcious*), or on separate plants (*diœcious*).

In many flowers which have both stamens and carpels the anthers open and the pollen is shed before the stigma is ready to receive it, while in others the time of the ripening of the stigmas and anthers is exactly reversed.

There are also many cases in which the anthers and stigmas are so situated relative to each other, that it is impossible for the pollen to be placed on its own stigma.

The effect of self-pollination in some plants is very remarkable: thus, in some cases, complete sterility is the result; in others, the development of the pollen-tube is so slow that should the same stigma be cross-pollinated, even after some hours, the pollen-tube developed in the latter case grows much faster and effects fertilization. This is known as *prepotency*. Again, instances are known in which self-pollination is actually poisonous, and causes the flower to wither and fall off.

To secure fertilization, the pollen must somehow or another be carried to the stigma, and the only agencies which can be utilized for this purpose are the wind, and various animals which can move from flower to flower, such as birds and insects. It is therefore quite easy to divide flowers into two groups, *Wind-fertilized*, and *Insect-fertilized*, according as the one or other method is employed.

Insect fertilization.—A flower which is fertilized by insects has generally a showy corolla or a sweet smell to attract insects, and possesses a special gland termed a nectary, which secretes a sweet juice forming in a great measure the food of the insects visiting the flower. Special colours, and special forms of the flower, are naturally evolved by the selective agency of the fertilizing insects. In other words, an insect-fertilized flower must show the insect where it is, either by its conspicuousness, or smell, and must develop the particular form, colour, or quality which is most attractive to the special kind of insects which visit it to procure the food they are in search of. In return, the insect benefits the flower by carrying its pollen from flower to flower and thus ensuring the perpetuation of its species.

Hairs and conspicuously coloured markings are present in many corollas: these and numerous other beautiful contrivances are all adaptations to secure Cross-fertilization. To prevent insects incapable of effecting pollination stealing the nectar, the nectaries are often concealed in the flower, the various markings are *path-finders* to guide the insect in the direction in which honey is secreted, and the irregular shapes of the corolla compel it to advance in certain definite directions that in so doing its body may come in contact with the anther and stigma. Many

contrivances are employed to ensure that the insect, on entering the flower, should deposit the pollen it has brought on the stigma before touching the anthers, and on leaving the flower should carry away fresh pollen to deposit on the stigma of another flower.

In open flowers like the Buttercup, Rose, Apple, Strawberry, &c., the insect when visiting the flower is obliged to touch some of the numerous anthers and stigmas, and pollen will not be placed on any definite part of its body; but in many flowers which have a more complicated structure, the insect is so directed that pollen must always be placed upon a particular part of its body, and on entering another flower of the same kind the stigma touches exactly the same spot, and thus effects cross-fertilization.

Flower of Cabbage.—The forms of flowers and the manner of their fertilization is one of the most attractive studies of Botany: nearly every flower adopts a different plan to ensure this end. As examples, we may consider the Cabbage and the Pea.

The various kinds of Cabbage, Mustard, Cress, Turnip, Swede, Radish, Charlock, &c., belong to a group of plants called the *Cruciferæ*, so named because the petals are four in number and arranged like a cross. The flowers of these plants have four sepals and four petals. The sepals (fig. 23, *c*) are triangular, green, and, although not joined together, form a kind of tube, which encloses and supports the petals. The petals are yellow, and in each two parts may be distinguished; a narrow stalk reaching to the top of the sepals, and a broad expansion spreading out at right angles to its stalk. Inside the stalks of the petals are found six stamens, and inside these again the pistil with

its stigma. The various members of the flower are crowded together; and when a bee visits the flower, and pushes its proboscis down to reach and suck the nectar, which is secreted by green glands at the base of the stamens, one side of its head touches the stigma and the other the anthers. During repeated visits to the flowers both sides of its head will become dusted with pollen. In flying away it will carry pollen on the sides of its head, and when alighting on another flower, as it reaches down to the nectaries, its head will touch the stigma with pollen and effect cross-fertilization.

The flowers of the Cabbage are largely visited by insects, and cross-fertilized; but should cross-fertilization fail, the anthers may bend and touch the stigma and self-fertilization be effected—but much better seed is produced from cross-fertilized flowers.

Fig. 26 (*after Baillon*). Flower of Pea (*Pisum sativum*).

Flower of Pea.—The mechanism by which fertilization is effected in the important group of the Leguminosæ is much more elaborate than in the Cruciferæ; as an example of this order we may study the flower of the Pea.

In this flower there are five sepals partially joined together, thus forming a cup with five triangular teeth.

The petals are also five in number, and on account of their different shapes, special names are given to them. The large petal, situated at the back of the flower, is the *standard;* a little below this is a pair of petals, the *wings*, which enclose another pair forming the *keel.* The standard is a broad semicircular petal, which, turning upwards, forms

the most conspicuous feature of this flower. On its face, at the bend, are two projections which fit into a pair of corresponding depressions in the wings, near their base. The wings are also brightly coloured. A little behind the depression just described, there is another depression caused by a hollow tooth-like outgrowth, projecting from the inner side of each wing. This tooth turns forwards and downwards, and fits into a depression in the keel. The wings and keel are in this manner firmly locked together, and cannot be separated without the application of a considerable amount of force. The keel at first sight appears to be one petal, on account of the two halves being firmly joined along their edge; but on examination there will be found to be two separate stalks, and their resemblance to the bows of a boat has given the name keel to these two petals. At the apex of the keel will be found a small conical pouch—the *keel-pouch*—which opens by a minute pore—the *apical opening*—through which the style emerges when the keel is pressed down.

Fig. 27 (*from Figuier*).

Corolla of Pea (*Pisum sativum*) dissected. The upper petal is the standard, the two side ones the wings, and the two lower the keel.

The stamens, ten in number, have their filaments partly united and partly free. The united portions form a sheath; this is split along the upper surface, and is the same length as the ovary which it encloses. The free portions are

prolonged beyond the sheath, and then turn upwards at right angles, bearing the anthers, which are enclosed in the keel-pouch. The nectar is secreted in the sheath, and can only be reached through the slit along its upper surface.

The pistil has a well marked ovary, in which a number of ovules may be seen suspended along its upper edge; the style turns upwards at right angles to the ovary, and is about half its thickness; at its extremity is the stigma; and below this, on the side towards the base of the flower, are a number of hairs extending from the stigma to about one

Fig. 28 (*from Baillon*).
Stamens and pistil of the Pea (*Pisum sativum*).

Fig. 29 (*from Baillon*).
Pistil of the Pea (*Pisum sativum*), showing ovary, style, and stigma.

third of its length, forming what is known as the *stylar-brush.*

The anthers shed their pollen just before the flower opens, filling the keel-pouch and covering the stylar-brush with pollen. If now the keel be depressed a little, the style is forced through the apical-opening, and a little pollen is swept out by the stylar-brush. The style resumes its original position as soon as the keel rises. After the anthers have shed their pollen they are withdrawn to the base of the keel-pouch, where they enlarge, and thus prevent any pollen falling to the base of the keel. Every time the keel is depressed a little pollen is swept out in this manner. Pollina-

tion is effected by bees. They alight upon the wings, which form a convenient landing stage, while endeavouring to procure the honey, and in order to reach the nectar, the proboscis must be pushed beneath the standard, and the standard and wings separated from each other. The force required for this purpose, together with the weight of the bee, presses down the wings, and therefore the keel with them, causing the end of the style to project through the apical-opening. The stylar-brush is thus brought into contact with the under side of the bee, and a few grains of pollen are placed upon it, and carried by the bee to another flower.

The force required to depress the keel is, however, too great for the majority of our bees; and hence it has been observed that the Pea is seldom visited by these insects, and the flowers are therefore, nearly always self-pollinated. The Pea is not a native of this country, but appears to have been introduced from the East, and its form is therefore better adapted for the visits of larger and more powerful species of bees.

Wind-fertilized flowers.—Hitherto we have considered insect-fertilized flowers, and must now pay a little attention to those which are fertilized through the agency of the wind. With these flowers there is no need for a showy, conspicuous corolla, and this part of the flower is therefore often very much reduced, or even altogether absent. The stamens produce a large amount of pollen, which is scattered in all directions by the wind. The quantity of pollen produced by some flowers of this kind is enormous. The so-called sulphur showers of the Scotch Fir are caused by millions of yellow pollen grains. Some few grains are carried to stigmas and pollinate them, while by

far the larger quantity is blown away and completely wasted. The stigma must be large, in order to collect any stray pollen grains which may happen to come within its reach. As examples of this method of pollination we may cite the Oak, Hazel-nut, Beech, Birch, Grasses, Sedges, &c., &c.

The Grass flower consists of several scale-like leaves, which enclose and protect the stamens and pistil. The stamens, although only three in number, produce a large amount of pollen. The filaments are very slender, and by increasing in length, push the anthers outside the scales, allowing the pollen to be blown away. The stigmas in a great measure resemble two minute feathers, and the pollen grains are readily caught by the arms of these feathers.

CHAPTER VII.

FRUIT AND SEED.

In the previous chapter the formation of the pollen-grains has been traced, and also the development of the ovule, with its integuments, nucellus, embryo-sac, and oosphere.

The pollen-grain, as we have seen, is in one way or another placed upon the stigma, and the stigma may then be said to be pollinated, the actual fertilization taking place when the pollen-tube has grown through the micropyle, and the nucleus of the pollen-tube has fused with the nucleus of the oosphere. The single cell formed by the union of these two nuclei, and known as the oospore, is the commencement of the new individual which appears on the germination of the seed. Consequent upon fertilization, changes take place in the oospore, the ovule, and the carpel, and these we must briefly consider.

Development of embryo.—After fertilization the oospore immediately surrounds itself with a cell-wall, and then commences to elongate in the direction of the axis of the ovule. It is unnecessary to consider the various divisions of the oospore; it will suffice to say that it does divide, and that the cells so formed, themselves divide and subdivide again and again, with the result that a miniature plant is formed, having stem, root, and leaves, which are usually known as plumule, radicle, and cotyledons or seed-leaves. The cells, which will become the epidermis,

ground, and fibro-vascular tissue, are clearly to be distinguished from each other. This young plant is known as the *embryo*, and is always so situated in the ovule that the apex of its root points directly towards the micropyle.

The embryo has usually either one or two seed-leaves, so that the flowering plants (with the exception of the Cone-bearing trees and their allies) are divided into those with one seed leaf or cotyledon (*monocotyledons*), and those with two cotyledons (*dicotyledons*). Although the discovery of the number of cotyledons drew attention to the difference between these groups, and gave to them their names, yet it is by no means the only mark which separates them.

The young embryo, although it has even when within the seed, the stem, root, and leaf, already formed, yet if placed in the soil would be incapable of further development and growth into a new plant, unless a considerable store of nutritious reserve material is placed at its disposal until it is able to support itself. Hence a considerable store of *proteid* (substances containing carbon, hydrogen, oxygen, nitrogen, and sulphur), and also of non-nitrogenous matter (starch, fat, oil, cellulose) is placed in the seed to be used by the embryo. The proteids in seeds are found in the form of small ovoid bodies, known as the *aleurone* grains, and may occur in the cell in company with the non-nitrogenous materials (fig. 30), or may be confined to special cells (fig. 34). The form of the non-nitrogenous reserve material is characteristic of many groups of plants; for example, starch is found in the seeds of Grasses, Leguminous plants (with the exception of the Lupin), Beet-root, &c.; oil in the seed of the Cruciferous plants, Poppies, Castor Oil, Composites, &c.;

and cellulose in the form of a very much thickened cell-wall, gives the characteristic hardness to the seeds of the Palm, Lily, Iris, &c.

Seed.—During the formation of the embryo and the storing of the reserve material, the cells of the nucellus are absorbed, and the integuments are the only part of the original ovule which remain, and these become the covering of the seed, technically termed the *testa*, which is often brown and hard for purposes of protection.

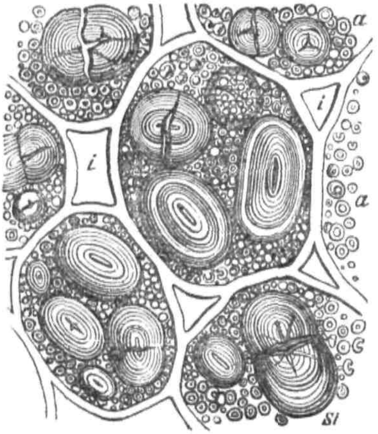


Fig. 30 (*from Sachs*).
Cells from the cotyledon of a Pea (*Pisum sativum*) still in the ripe seed. The large grains (*St*) are starch grains; the small granules (*a*) are aleurone grains; *i*, intercellular spaces.

It is usual to divide seeds into two classes, *exendospermous* and *endospermous*: these were formerly termed *exalbuminous* and *albuminous*, but it is better to discard the older terms to avoid any confusion with the term albumin. In the seeds of the first of these classes, the embryo fills up the entire cavity enclosed by the testa, the reserve material being stored up in the cells of its own seed-leaves—the cotyledons. This formation of the seed is found in many families of plants, such as the Cruciferæ, Leguminosæ, &c.

In the second class, the embryo occupies only a portion of the space enclosed by the testa, the rest of the space

being filled up by special cells, known as the ***endosperm***, and this tissue contains the reserve materials. Examples of this kind of seed are found in Grasses, Composites, Mangold, Carrot, Parsnip, &c.

When sufficient reserve material has been stored up in the ovule, and the embryo has reached the proper stage in its development, it is said to be ripe, and is then known as the seed. During the process of ripening, the seed loses a considerable amount of water, and its cells become dormant, and remain in this condition until germination commences.

In the meantime, changes have been taking place in the carpel, and about the time that the seed is ripe, the carpel ripens into the *fruit*. The walls of the ripened carpel are termed the *pericarp*. It is important to clearly distinguish between the terms fruit and seed, meaning by the former the ripened carpel and by the latter the ripened ovule.

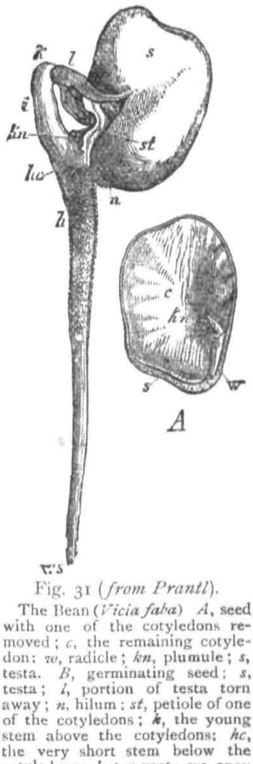


Fig. 31 (*from Prantl*).

The Bean (*Vicia faba*) *A*, seed with one of the cotyledons removed; *c*, the remaining cotyledon; *w*, radicle; *kn*, plumule; *s*, testa. *B*, germinating seed; *s*, testa; *l*, portion of testa torn away; *n*, hilum; *st*, petiole of one of the cotyledons; *k*, the young stem above the cotyledons; *hc*, the very short stem below the cotyledons; *h*, tap root; *ws*, apex of tap root; *kn*, bud in axil of one of the cotyledons.

The Bean (fig. 31), or Pea, is an example of an exendo-spermous seed, the structure of which can easily be examined by first soaking it in water for about twelve hours, and then with a sharp knife removing the skin (testa) (fig. 31, *A*, *s*):

the black mark on one side, *hilum*, is the part where it was attached to the pod. After removing the skin, the radicle is seen as a conical point (*A*, *w*) beneath the hilum; its apex is just beneath a minute aperture in the testa, through which a drop of water may be squeezed in a soaked seed: this is the micropyle, and at this point the radicle will emerge. The two seed leaves (*A*, *c*) are found as thick, irregular-shaped discs, which can be readily separated from each other, but will be found to be connected, one on either side, with the base of the radicle.

The plumule (*Kn*) is a continuation of the radicle beyond the connections with the cotyledons. The seed therefore contains only the embryo, its large seed-leaves occupying nearly the whole of the seed. The reserve materials are found stored in cells of the cotyledons—the non-nitrogenous ones in the form of starch, the nitrogenous as aleurone grains lying between the starch grains (fig. 30).

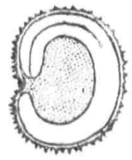


Fig. 32 (*from Figuier*). Section of seed of the Corn-cockle (*Lychnis githago*). The shaded central portion is the endosperm, surrounding this is the embryo.

The seeds of Cruciferous plants (Turnip, Cabbage, &c.) should be examined in the same way. It will, however, be found that in many of these plants the cotyledons are rolled or twisted, and do not remain flat as in the Bean. These seeds contain a large proportion of fatty oil, present in a finely divided state in the cell protoplasm: it replaces the starch as the chief non-nitrogenous material.

A diagram of an endospermous seed of the Corn-cockle (*Lychnis githago*) is given in fig. 32. On the outside is the testa, thick, hard, and covered with numerous projec-

tions. The central portion of the seed is occupied by the endosperm, and the embryo forms a nearly complete ring surrounding this. Our diagram passes through the whole length of the embryo, the line in the upper part indicating the position of the seed leaves.

As another example of an endospermous seed, we may examine that of the Grasses. A grain of corn, botanically speaking, is not a seed, but a fruit; the pericarp remaining in contact with the testa, can be easily separated as a translucent membrane. The embryo in the Gramineæ is situated on one side of the endosperm: in the Wheat, Oats, and Barley, it will be found near the lower end of the grain on the opposite side to the furrow. As a type of the Grasses, the Indian corn, on account of its larger size, may be conveniently examined.

The corns should be soaked in water for about twelve hours, so that the outer membrane may be easily removed, and the seed should be halved longitudinally through the embryo, which may be detected as a white oval patch on one side of the grain (fig. 33, *A*). The endosperm is partly white and mealy (*ME*), and partly yellow (*HE*); the latter part is hard and horny, and being on the outside, gives to the grain its characteristic colour. Separating the endosperm from the embryo is a structure which occurs only in this group of plants—the *scutellum*, *Sc.*—this is really the cotyledon, which almost entirely envelopes the embryo. It never expands, and becomes green, but remains in the seed, and is modified to abstract the reserve materials and convey them to the embryo. With slight magnification, or even with the naked eye, the plumule (*Pl.*), and the radicle (*Rad.*) can be easily made out, the former having already several leaves developed.

The special layer of cells of the scutellum (*Pal.*), in contact with the endosperm, can be distinguished from the others by their oblong shape and regular arrangement.

Starch forms the non-nitrogenous reserve materials. In the mealy portion of the endosperm (fig. 34, *C*, *ME*), the starch grains are crowded together in the cells, but in the

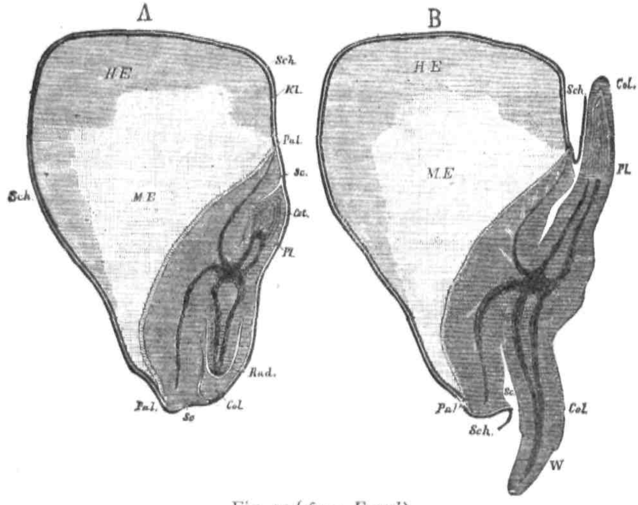


Fig. 33 (*from Frank*).

Longitudinal sections through a grain of Indian corn (*Zea mais*). *A*, before germination; *B*, at the commencement of germination; *Sch.*, the fine membrane formed of pericarp and testa; *ME* the mealy, and *MH* the horny, endosperm; *sc.*, the scutellum; *Pl.*, plumule; *Rad.*, radicle; *Pal.*, cells of scutellum in contact with the endosperm.

hard and horny part they are compressed into a very dense mass (*D*, *HE*).

The nitrogenous reserve materials are not contained in the same cells as the starch, but are found in the external layer (*D*, *Kl*) of the endosperm.

Germination.—Under favourable conditions of temperature, moisture, and air, the cells of the embryo, which have hitherto been in a dormant condition, resume their activity and commence to absorb water to restore turgidity to the cells.

The first sign, then, in germination is the swelling of the seed.

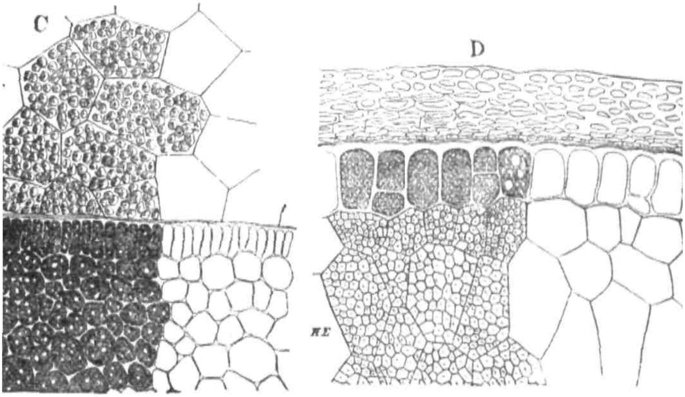


Fig. 34 (*from Frank*).

Portions of an Indian corn grain more highly magnified. *C*, the junction of scutellum and endosperm; *Pal.*, the ferment secreting cells of scutellum; *ME*, mealy endosperm; *D*, the outer part of a grain; *Sch.*, the pericarp and testa; *Kl.*, the proteid containing cells; *HE*, horny endosperm.

The cells of the root next divide and grow, and the root tip is pushed out of the seed through the micropyle. The micropyle, it will be remembered, is the weakest part of the integument, and for this reason is chosen as the spot whence the root can most easily emerge. The young root immediately commences to penetrate the earth, and soon begins to branch and to develope the root system. After the root has emerged, the plumule next appears and

grows upwards, and as soon as possible leaves are exposed to the light and air. That the root must always be the first to emerge, is evident when it is considered that as soon as the leaves appear transpiration commences, and a supply of water must be at hand for this purpose; it is then only after the root has obtained a fair hold, and has begun to develop its root-hairs, that the leaves expand. These leaves may or may not be the cotyledons. In some plants, Melon, Turnip, Mustard, the cotyledons are withdrawn from the seed and expand as the first green leaves, which are soon followed by other foliage leaves, these we may call *aerial-cotyledons*. In other plants (Pea, Field-bean) the cotyledons never leave the seed, and remain therefore always buried—these are known as *subterranean-cotyledons*, and the leaves succeeding them are the first to commence assimilation.

If the seed has no endosperm, the whole of the reserve material is already in the young plant, but in the endospermous seeds some adaptation is necessary to transfer this to the young plant: generally it is effected by means of the cotyledons, and these, in the case of aerial-cotyledons, only expand after the endosperm is all absorbed.

Ferments.—The reserve material in the seed, whether it is endospermous or exendospermous, must be changed into a soluble substance capable of passing from cell to cell, through the cell-wall, before it can be used by the embryo. This is effected by means of *ferments*, a name given to a class of bodies which have the power of changing certain substances into others of which they form no part. A ferment known as *diastase* has the power of converting starch into sugar, in which state this non-nitrogenous substance can readily pass through cell-walls. Another

ferment in a similar manner also converts cellulose into sugar.

For example, when a grain of one of the cereals commences to germinate, a ferment secreted in the prismatic cells of the scutellum (fig. 34, *Pal.*) disintegrates the cell-walls of the endosperm, and almost immediately afterwards the starch grains are attacked by the diastatic ferment. The disintegration of the endosperm gradually proceeds from the scutellum until all the endosperm has been rendered soluble and transferred to the embryo. The growth of the scutellum keeps pace with the disintegration of the endosperm, so that it always remains in contact with it.

In the same manner, by means of ferments, the aleurone grains are rendered soluble and transferred to the embryo.

The activity of a ferment is subject to various external conditions of temperature and moisture, which are the same as those which promote the germination of the seed.

Conditions of Germination.—For the germination of seeds, there is a certain temperature at which it takes place most readily, which may be called the optimum, and the activity of germination becomes less and less as the temperature is either above or below this point.

The maximum temperature at which seeds will germinate differs very much with different kinds of seeds. No seed has been known to germinate at a temperature above 50° C. (122° F.) although Indian corn has been known to germinate at a temperature very little below this. The maximum temperature for *Wheat*, *Barley*, *Oats*, *Cabbage*, and *Peas* is from 31° C.-37° C. (77° F.-88° F.), and that for *Clover* and *Lucerne* 37° C.-44° C. (88° F.-111° F.).

The minimum temperature for the germination of most

common seeds is about 4·5° C. (40° F.), although some seeds have been known to germinate on ice at the freezing point. The minimum for Indian corn is about 10° C. (50° F.)

Sachs has determined the minimum and maximum for the germination of Wheat and Barley to be 5° C. (41° F.) and 29° C. (84° F.) respectively, while the optimum for Barley is 38° C. (100° F.) and for Wheat 42° C. (107° F.).

Moisture.—A seed when ripe contains little moisture. The superfluous water is got rid of during the process of ripening; and so, before germination can commence, a large amount of moisture must be absorbed by the seed. In the case of Red Clover, Nobbe found that the seeds absorbed as much as 105 per cent. of water, and in the case of Wheat 60 per cent. of water, before germination commenced.

Access of free Oxygen.—Seeds again are incapable of germinating without a supply of oxygen. The ordinary air being composed of about one-fifth oxygen, supplies the requisite amount of this gas. It is immaterial what gas dilutes the oxygen, and hence seeds are capable of germinating in mixtures of four-fifths carbonic acid or hydrogen, and one-fifth oxygen; but it is not possible for germination to take place in pure carbonic acid, hydrogen, or nitrogen.

The seed, when placed in the ground with the above conditions satisfied, after a certain period commences to germinate.

The time from the sowing of the seed to the protrusion of the radicle varies in different seeds.

Fruit.—The fruit, like the seed, may be dry and hard, fleshy or hairy; it may contain an enormous number of seeds, but instances are not uncommon in which the fruit has only one seed. In the latter case, it is not necessary

that the fruit should open to allow the seed to escape, and then the walls of the fruit become the protective envelopes. When the fruit contains more than one seed, some mechanism is employed to open the fruit, to allow the seeds to escape, and to prevent them being all sown on one spot. The parent plant living on one spot exhausts the nourishment from the particular piece of ground on which it grows, and hence, if its seeds were to fall near the parent, they would alight upon ground to some extent impoverished and would not be able so successfully to compete with their various enemies. It is therefore beneficial for any particular plant that its seed should not be sown too near the parent, and also, in order that it be not exterminated, that some of the seeds should be scattered very widely, and to this end many wonderful contrivances are adopted. As in carrying the pollen-grains, so here the agency of various animals and of the wind is brought into service to disseminate seeds and fruits.

Wind distribution.—Seeds or fruits which are adapted to be distributed by the wind are characterized by being very light, and may be either small, thin, hairy, or winged, by all which means they can more readily float in the air and be blown to considerable distances.

Seeds like those of the *Field Poppy*, being very small and light, are easily scattered in all directions by the wind. In these instances the fruit contains many seeds, and opens by small holes, through which the seeds escape during gusts of wind.

Thin, flat seeds are found in the Parsnip, Tulip, &c.

Hairy seeds or fruits are very common—examples of the former are found in Willows and Poplars, and of the latter we need only mention such familiar examples as the

Dandelion, Thistle, Coltsfoot, &c., in which the calyx is represented by a number of very fine silky hairs, situated on the top of the fruit. The prevalence of these plants everywhere is a matter of common observation, and is due to the ease with which their fruits are blown about.

In the Ash, Sycamore, Birch, &c., the fruit is prolonged into wings to assist in the dispersal of their seeds.

Animal distribution.—Seeds or Fruits intended to be distributed by animals are either succulent and eatable, or else are covered with hooks, so that they may adhere to the fur or feathers, and be carried by this means to fresh localities.

To the former category belong all fruits which have become fleshy and edible on purpose that they may be devoured by birds and other animals, and so be carried to a distance, and thus ensure the dispersal of their seeds. The embryo, however, in these cases, must be protected by a hard covering, in order to prevent its destruction during the processes of digestion and mastication.

The Cherry and Plum are fruits of one carpel, in which the external tissues have become soft and pulpy, and the internal ones very thick-walled, forming the so-called stone.

Other examples occur; in the Holly, for instance, the fruit is formed of more than one carpel, but with the same purpose in view. In the Apples, Pears, &c., it is the stalk on which the flower is borne which becomes specially swollen and eatable, and in the Strawberries, Hips, &c., the receptacle forms the edible fruit; these are known as *false fruit* to distinguish them from *true fruits*, which are ripened carpels only.

Hooked fruits are very common, and many plants, Cleavers (*Galium*), Avens (*Geum*), owe their wide dispersal

to the presence of many tiny hooks which are developed on their fruits. Among agricultural plants, the Carrot affords a very good example of a hooked fruit.

It is not only the fruit upon which hooks are produced, but the seeds of various kinds of plants (such as the Forget-me-nots, which are weeds in cornfields) are in the same way transported from place to place by hooks on the calyx; and many other instances might be given.

CHAPTER VIII.

FOOD.

In the introductory chapter we pointed out that plants require a supply of food, and that this food must be obtained in an inorganic form. We have now to inquire what substances compose this food, from what sources they are derived, and by what means the plant absorbs them.

In describing the protoplasm, it was learnt, that although its exact chemical composition could not be determined, yet it belonged to a class of substances known as proteids, and which are made up of carbon, hydrogen, oxygen, nitrogen, and sulphur, and that the cell wall is made up of the first three of these. Hence, in order that new cell wall and protoplasm may be formed, a supply of these elements must be available. But direct analysis of a plant shows that certain other elements are always present—namely, potassium, calcium, magnesium, iron (in green plants), and sometimes chlorine.

There are thus two groups of food elements—those which take part in building up the plant; and those which, although they are not used in the actual structure of the plant, are always present, and in the absence of which the various chemical changes which are continually taking place in the plant cannot proceed. A convenient definition then, of food will be—"those substances which are used

in building up the plant, or which promote the various chemical changes which are necessary in constructing it."

The constituents of plant food have been determined by direct analysis of the plant, and by its cultivation in various nutritive solutions.

The various steps in the analysis of a plant are (1) to drive away the moisture; (2) to burn the plant, and collect the gases given off during the combustion; and (3) to analyse the ash.

In the first of these processes, when a plant is thoroughly dried at the temperature of boiling water, a large amount of moisture is driven off, which can easily be collected.

The following table, taken from Johnson's "How Crops Grow," shows to what an extent water enters into the composition of a living plant, thus :—

	Per cent. of Water.
Meadow grass contains . . .	72
Red Clover ,, . . .	79
Cabbage ,, . . .	90
Potato tubers ,, . . .	75
Carrot ,, . . .	85
Turnips ,, . . .	91
Pine-wood ,, . . .	40

In plants dried at the ordinary temperature, much of this water escapes, but a good deal remains to be driven off at higher temperatures. Thus air-dried plants have been found to contain as follows :—

	Per cent.
Meadow grass	15
Red Clover	17
Straw and chaff of Wheat, Rye, &c. .	15

	Per cent.
Bean straw	18
Wheat grain	14
Indian corn grain . . .	12

In making hay, therefore, the amount of moisture in meadow grass is reduced 57 per cent., and in Red Clover 62 per cent.

This large amount of water, which is composed entirely of oxygen and hydrogen, would be contained principally in the cell sap, and would be required to maintain the cells in a turgid condition.

During combustion of an air-dried plant the following elements are generally given off as gases or vapour:—carbon, hydrogen, oxygen, nitrogen, and small quantities of sulphur and phosphorus.

The following table, taken from Johnson's "How Plants Grow," shows in what proportion these elements are used in building up the plant:—

	Wheat grain.	Wheat straw.	Potato tubers.	Peas.	Clover hay.
Carbon . . .	46·1	48·9	44·0	46·5	47·4
Hydrogen . .	5·8	5·3	5·8	6·2	5·0
Oxygen . . .	43·4	38·9	44·7	40·0	37·8
Nitrogen . .	2·3	0·4	1·5	4·2	2·1
Ash, including Sulphur and Phosphorus	2·4	7·0	4·0	3·1	7·7
	100·0	100·0	100·0	100·0	100·0

After combustion a quantity of ash remains, which is very small compared with the amount burnt. This ash may contain a little carbon, oxygen, sulphur, and phosphorus, but its chief constituents are mineral matter, of which the principal components are—

Potassium	Iron
Sodium	Phosphorus
Calcium	Silicon
Magnesium	Chlorine

Besides the above, certain other elements are sometimes found, which do not come under our definition of food, and may therefore be neglected.

We are now in possession of all the elements which compose the food of plants, and these we will proceed to consider in detail.

Carbon.—In the chapter on the leaf we have dealt fully with the absorption of carbon by the green plant in the form of carbonic acid, and the manufacture of starch as the first visible product of assimilation, and have learnt that it is required in the construction of cell wall and of protoplasm.

The source of carbon for the green plants is the air. The plants which do not possess chlorophyll, and therefore cannot assimilate their own carbon, will be considered in Chapter IX.

Hydrogen, as one of the constituents of water, is absorbed in this form by all plants. It takes part in the formation of cell wall and protoplasm.

Oxygen, like hydrogen, is absorbed as a constituent of water; but it is also taken in from the air. A supply of oxygen we have seen (p. 11) is necessary for respiration: this is obtained from the free oxygen of the atmosphere, and is given off as carbonic acid. The oxygen used in constructing the plant is derived from the combined oxygen of the water absorbed.

This element is a constituent of cell wall and of protoplasm.

Nitrogen, as a constituent of protoplasm, must be available as one of its food elements; and plants supplied with a due proportion of this substance are stronger, more vigorous, and consequently weigh very much more than those in which this supply has been deficient. We must not, however, consider that the increased weight is owing entirely to an increased amount of nitrogen; for although the weight of nitrogen is certainly greater, the increase in weight is chiefly due to the non-nitrogenous compounds such as starch, cellulose, &c.; the explanation being that a requisite supply of nitrogen, by improving the health of the plant, enables more and more protoplasm to be formed, and hence additional cells to be constructed, thus causing greater luxuriance in growth. Furthermore, the cells being more numerous and vigorous, can manufacture more readily starch and other reserve materials, thereby producing a greater yield in grain and straw. This gain of carbo-hydrates has been found by Sir J. B. Lawes and Dr Gilbert (Agric. Stud. Gazette, vol. iv.) to be as much per acre, as 36·5 lbs. in Wheat, 32·2 lbs. in Mangold-wurzel, and 16·5 lbs. in Potatoes, for one lb. of nitrogen when applied as 86 lbs. of nitrate of soda per acre.

Although, roughly speaking, four-fifths of the atmosphere is nitrogen, and it pervades all the tissues of a plant, yet—except in certain plants—this source of nitrogen is not directly available as plant food, and numerous experiments most carefully performed, have shown that the stem and leaves of a green plant cannot make any use of this large supply.

The inorganic nitrogenous salt most suitable for plant food is that of nitric acid combined with potash, soda, or lime; thus forming nitrate of potash (saltpetre), nitrate of

soda, or nitrate of lime. It is on this account that all the nitrogen in farm-yard manures, and in all organic nitrogenous compounds, must be converted into nitric acid, undergoing a process known as *Nitrification.* The nitrification, it is now known, is accomplished by certain minute organisms in the soil, allied to the Bacteria. These decompose the organic bodies, and set free first a nitrite; this is again broken up by other similar organisms, and nitric acid is formed, which combines with the potash or lime in the soil to form a nitrate. In this form nitrogen is capable of absorption by the plant.

The process of nitrification is almost always taking place. Moisture and warmth are essential to its promotion, but too much water hinders or even stops the process, so that in marshy lands it is comparatively inoperative, and in excessive cold it almost entirely ceases.

The amount of air too, in the soil, has an important influence on nitrification: porous soils and those broken up and well exposed by tillage, are most favourable to the action of the micro-organisms.

Sources of Nitrogen.—Besides the nitrogen given to land in manures, a small quantity is continually being supplied by rain, which dissolves the small amounts of ammonia and of nitric acid in the air, and carries them to the soil. The amount of nitrogen thus deposited is estimated to be about 3·4 lbs. per acre.

Another source of nitrogen is that provided by the decay and nitrification of Leguminous plants. These do not obtain their nitrogen from the soil in the ordinary manner, but by a certain peculiar process which will be described in Chapter XI.

From dead animal and vegetable matter after nitrifica-

tion, and from the air, as just described, plants in the wild condition derive their nitrogen, and Gilbert and Lawes have shown that Barley, even after twenty-five years in the same soil, and with no manures supplied to it, gave a fair crop. But with cultivated plants, the yield of a crop is greatly increased if nitrogen be supplied artificially in manures.

Sulphur, beyond being a constituent of protoplasm, is not known to be of any further use in plant economy. It is generally absorbed from the soil as a sulphate, such as that of magnesium or potassium, though calcium sulphate (plaster of Paris) is the one which is most advantageous for this purpose. Supplies of sulphur may be obtained from kainit, and sulphate of ammonia. The quantity of sulphur required is small, but it is an essential element of plant food, and even so small a quantity must be available.

Phosphorus is well known to be highly beneficial to plants, but at present the exact function of this element is obscure. It appears, however, that its presence greatly promotes the assimilation of nitrogenous compounds, and it is supposed to be a constituent of the nucleus, and of the chlorophyll grain. A small quantity is essential for plant life.

Iron, although it is not a constituent of either cell wall or protoplasm, is universally found, though often in very small quantities, in the ash of green plants, and these never grow so well when it is absent.

The presence of iron is of importance in the development of chlorophyll, although it takes no part in the composition of the chlorophyll corpuscles. If a seed be planted and grown in a soil absolutely free from iron, its first few leaves will develop normally, but the succeeding

leaves become paler, or even altogether white, signifying the incomplete development of the green pigment; but if a trace of iron be supplied, as a weak solution of one of its salts to either the roots or leaves, the green pigment speedily becomes apparent, and the development of the plant proceeds in the ordinary manner. The quantity of iron contained in the seed is small, and suffices only for the first stages of growth. For further development of the young plant, it must be supplemented.

Potassium is found to be present throughout the whole plant, although, like iron, this element takes no part in its actual construction. It is, however, of great importance, and plants cannot perfectly develop to produce fruit and seed without it. This is easily proved by growing plants from seed, in soils destitute of potash. At first the leaves may be fully developed, owing to the presence of a small amount of potash in the seed, but afterwards, when this is exhausted, further development ceases.

Potassium is especially important for plants which store up a large amount of starch or sugar, and the proportion found in such is large—for example, Potato tubers contain 2·27 per cent., Mangold 3·47, Sugar-beet 5·0. It is absolutely necessary for the formation of starch, for although all other conditions necessary for this purpose are fulfilled, in the absence of potassium the chlorophyll corpuscles are unable to manufacture starch.

The most useful salt appears to be the chloride, and next to this the nitrate, although all the potassium salts, being soluble in water, may be absorbed. The effect, however, of any salt appears to vary according to the kind of plant, and nature of the soil. Kainit—sulphate of potash and magnesium, with chloride of sodium—is an

excellent medium for supplying this element to the soil. Its place cannot be supplied by sodium.

Calcium and Magnesium are invariably present in the ash of plants, but very little is known of their importance. Calcium is absorbed as a phosphate, sulphate, or nitrate, and, like magnesium, may be absorbed as any of their salts. The chlorides, however, of these metals are injurious.

Calcium is commonly found as rhomboid crystals of calcium oxalate, in leaves and leaf stalks, sometimes as bundles of long needle-shaped crystals (*raphides*), and sometimes in the form of carbonate. According to some authorities, calcium is of use to neutralise the oxalic acid which is formed in the plant cell during the processes of metabolism.

Magnesium is found in the plant in very small quantities, being more abundant in the seed than in the leaves.

Silicon is one of the most widely distributed elements in nature, in the form of an oxide—silica. This is absorbed by plants in the form of a silicate, and is largely deposited in the cell walls of certain plants, notably the Grasses, and the Horsetails (*Equisetum*). In the straw of Cereals it varies from 40 to 70 per cent., imparting great hardness, and it was formerly supposed that this element was necessary to these plants for forming a sufficiently strong stem. It gives greater firmness, but plants in which this element so largely occurs have been grown quite healthy, and have attained their full development without this substance, so that silicon therefore plays no essential part in the plant nutrition.

Chlorine occurs in all plants, but in a very small percentage, being absorbed in the form of a chloride. To certain plants, as the Buckwheat, the presence of this element is necessary for their full development, but very little is known of its exact uses to the plant.

Water Cultures.—Experimental cultures to determine the relative importance of the various food elements, and the amounts necessary to be supplied as well as the best form in which to supply them, are easily made by the method of water cultures, or by growing plants in soils of known composition.

In the method of water cultures, plants are grown with their roots in various nutritive solutions. For this purpose tall jars holding about a litre and a half of water are necessary, to which the various food elements can be added. The plant subject to the experiment must be held so that its roots are submerged, while its stem and leaves are allowed to grow freely into the air.

Plants to be used for these experiments should be raised from seeds carefully germinated on damp filter paper, or powdered quartz, and then securely fixed to the underneath side of corks, which fit the jars, and are perforated so that the stems may emerge. The roots must be in the water, but the jars must not be filled so that the seed is in contact with the water.

A very convenient solution to use for this purpose is—

Water (distilled)	1000	grammes
Potassium nitrate	1·0	"
Calcium sulphate	·5	"
Magnesium sulphate	·5	"
Calcium phosphate	·5	"
Trace of iron sulphate	...	"

This solution contains all the elements of plant food in suitable proportions; and healthy plants can be grown when it is supplied to their roots. Care must be taken to renew the solution frequently, and to keep it in darkness to prevent the growth of algæ.

It will be noted that the growing solution is very dilute. Experiments show that a solution stronger than five per thousand is injurious, and if weaker than one half per thousand, it is too dilute to be of any service. In this connection, it will be remembered (p. 55) that solutions stronger than five per thousand hinder transpiration. In Chapter II. it was explained, that a cell is only maintained in a state of turgescence by the power which the substances dissolved in the cell sap have of absorbing water from weaker solutions; and if the nutritive solutions are more concentrated than the cell sap of the root hair, it is obvious that the root hairs will be plasmolysed, and they will lose water instead of absorbing it: and the current of water ascending the stem may even be reversed. For this purpose, the experiment described on p. 32 may be used, for if the plant be watered with a solution of common salt, after a short time, when the root hairs are plasmolysed, they will draw water from their neighbours, and the water in the tube will be seen to slowly descend.

These facts have an important bearing upon the application of artificial manures, and show us why these food substances must be supplied in small quantities for their proper assimilation by the plant.

It has been found that each substance is absorbed at a certain percentage, which, however, is not the same for all. Nitrate of potash is absorbed at a concentration of 2-5 per thousand: if therefore it is supplied in solution stronger than this, the proportion of water absorbed is greater than the potassium nitrate; but if the solution is weaker, the proportion of water absorbed is less.

The Indian corn (one of the Grasses) will be found a suitable plant for experiments whereby the deleterious

effect of omitting any of these elements of plant food can be readily determined. Thus, if a number of these grains are germinated, and several of equal vigour selected, one may be grown in distilled water, a second with the complete solution, a third with no nitrogen, a fourth with no sulphur, and so on. It will be found that the plant in the first jar, with no food supplied to it, and whose development is entirely derived from the reserve materials in the seed, is very weak and feeble, only a few leaves and attenuated roots being produced; in the second jar, a healthy and vigorous plant will be developed; in the third jar, a plant little better than the first, showing how important the supply of nitrogen is to these plants. The absence of sulphur and phosphorus also will retard the development of their respective plants, but not in such a marked degree as in the case of the withdrawal of nitrogen.

The solutions may be varied to any extent, and it is by countless experiments upon various plants, that the part played by each element has been ascertained.

The method of water cultures is hardly suitable for land plants, whose roots require to be in soil for the normal development of root hairs. In order to provide better conditions for these, artificial soils are employed which contain no nutriment—such as pounded quartz—and are watered with the different solutions. A great number of experiments have been tried in this way, and our illustrations, taken from photographs of culture experiments undertaken by Prof. Wagner of Darmstadt and kindly lent by Messrs Albert & Co., show very effectively the starvation which results when any one food element is not procurable by the plant.

Figures 34 and 35 illustrate experiments on Wheat

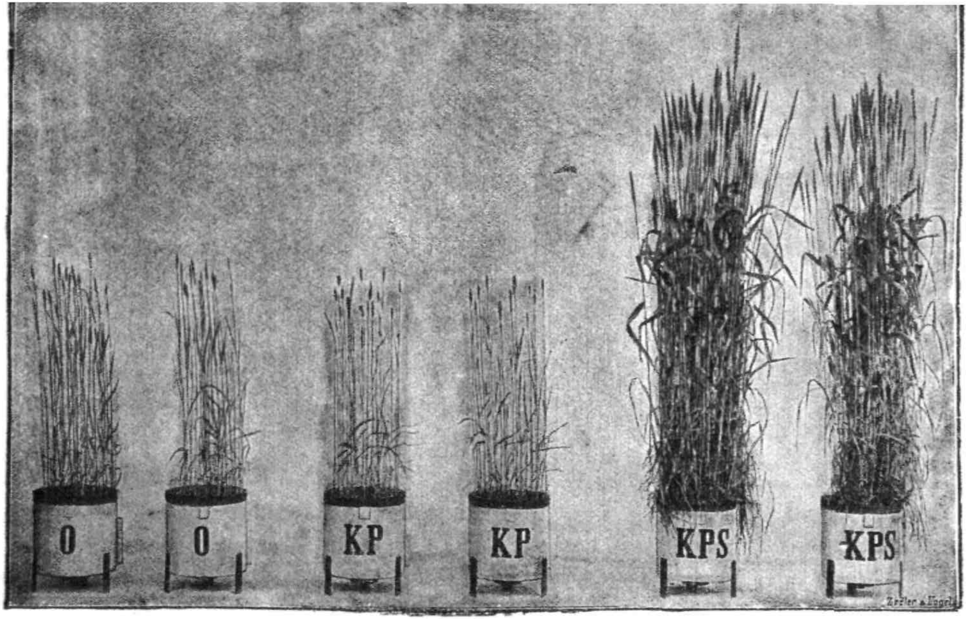
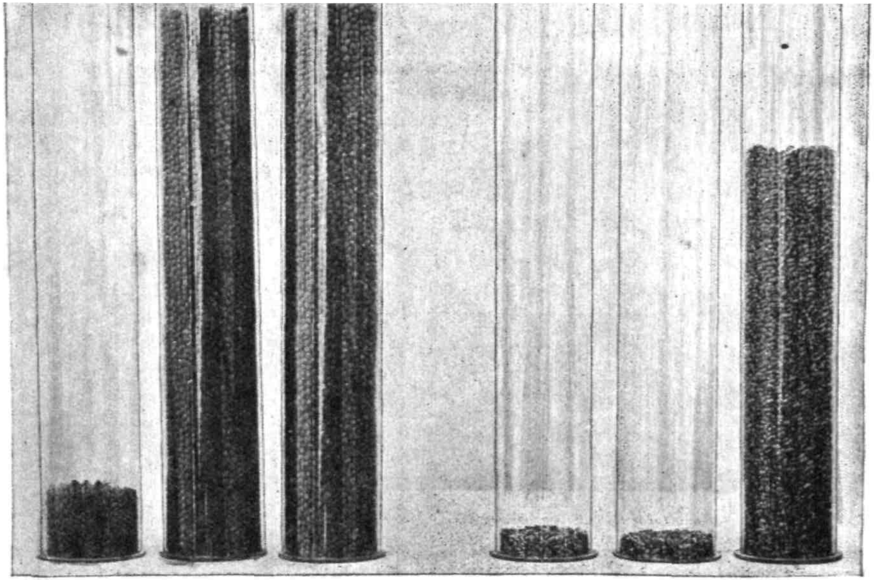


Fig. 34 (*after Wagner*).
Experimental cultures of Wheat.



Vetches. Wheat.

Fig. 35 (*after Wagner*).

Yield of grain from experimental cultures.

grown in pots (fig. 34) without manure (O); with potash and phosphoric acid but no nitrogen (K.P.); with potash, phosphoric acid, and nitrogen (K.P.S.). The yield of grain from these same plants is represented in fig. 35. The glass cylinder on the extreme right contains the grain (16·3 oz.) produced by the plants grown in pots K.P.S.; the next jar that (·75 oz.) from the plants in pots K.P.; and the next one, the grain (·8 oz.) from plants in pots O.

The effect of the absence of one element is very strikingly shown both in growth of plant and in the yield of grain; for in the case where potash and phosphorus are both present, but there is no nitrogen, the development is no greater than when no manure is supplied, whilst the improvement in growth and yield in these plants when nitrogen is added is very remarkable.

Absorption of Food.—Many substances present in the soil in an insoluble state are afterwards found in the plant, and must therefore have been rendered soluble before absorption. This can be accomplished in one or two ways.

The cell sap of the root-hairs has an acid reaction, and it permeates the protoplasm and cell wall, thus supplying the means of dissolving certain insoluble salts. Roots grown in contact with a slab of polished marble eat away the marble where they are in contact with it, and an impress of the complete arrangement of the roots is left in the marble.

Carbonic acid when present in the soil is dissolved in the water, and although a weak acid, it has an appreciable effect in increasing the power of the solubility of water.

Many insoluble compounds are rendered soluble by the decomposition occurring in the soil during the processes of decay, and also by the action of various manures.

By one of the foregoing methods, the plant food, when in an insoluble state in the soil, may be rendered soluble, and care must be exercised in supplying food, to present it in either a soluble form or else in one which is easily rendered soluble. If this is not done, it may never be dissolved and remains therefore unavailable, or else too much of the plant's energy is taken up in converting it into an available form, and impaired development may be the result. In this context, it should be remembered that *each element is most advantageously absorbed in the form* of certain definite salts.

Plants of different kinds, though growing together in the same soil, do not absorb the same proportion of mineral matter, and the ash of plants grown side by side does not contain the same quantities of these substances, on which account, roots are often erroneously said to have a "selective power." This is well shown by the analyses of silica in Grasses and Leguminous plants.

Thus, 100 parts of	Meadow hay	contain	27·	Silica
"	"	Wheat straw	"	67·5	"
"	"	Red Clover	"	2·57	"
"	"	Pea straw	"	6·83	"

This so-called "selective power" is true not only of such widely different plants as those just mentioned, but even of varieties of the same species; and further, the analysis of plants of the same variety but of unequal vigour, grown on the same soil and under similar conditions, gives different results, and the composition of a plant varies according to its vigour and conditions of growth.

The explanation of this apparent "selective power" is readily afforded by considering how a plant's food is absorbed.

The cells of the root-hairs, when turgid, will absorb any substance dissolved in the water surrounding them which they do not already contain in the same degree, until an equal degree of concentration is obtained on both sides of the cell wall; this substance is similarly passed on to the next cell, and it is obvious that a further amount must be absorbed, and the process repeated, until the whole plant is permeated. If the substance is one which is continually being converted to the uses of the plant, the equality of concentration can never be maintained,—and its absorption is constantly taking place; but if it is not used, there will be a time when the plant and the soil contain the same percentage, and therefore no additional supplies can be absorbed.

The absorption of silica illustrates this very well. The silica absorbed by the grass roots is deposited in the cell walls of the haulms, rendering them very hard, and is thus removed from the field of action; more silica is therefore absorbed, and the large amount of this element found in these plants is explained.

In Leguminous plants, on the contrary, the silica is not deposited, but remains in solution, consequently when the plant is saturated silica ceases to be absorbed, and these plants contain relatively a small amount of it.

Exactly the same process takes place with all elements capable of being absorbed, and this explains why so many substances are found in the ash in addition to those mentioned, some of which are of no use, and others even poisonous.

These considerations give the key to the principle of the "Rotation of Crops," by showing how different plants require and absorb their food elements in different

proportions. Each crop therefore exhausts the food constituents in certain proportions from the soil, and so leaves it in a condition unfit for the profitable cultivation of the same crop in the following season, though the soil may still contain all the food elements necessary for plants of a totally different kind. A judicious succession of crops secures that the full value is obtained from manures, the residue of one crop being utilised by those succeeding it, and the health of the crop is not impaired by imperfect nourishment.

The various food substances are not absorbed with equal vigour during the whole life of the plant. The absorption depends, as we have seen, on the activity with which they are changed and used in the plant, and so at one period of the plant's life it requires more of a particular food element than at another. This is well brought out by a very interesting series of analyses of the Oat by Bretschneider, a full account of which will be found in Johnson's "*How Plants Grow.*" Bretschneider divided the life of the Oat into five periods, and at the end of each he analysed the produce of a square rod of land. His periods were—

1st period.—		Four to five leaves developed.
2nd	,,	Plants were headed.
3rd	,,	Full bloom.
4th	,,	Beginning to ripen.
5th	,,	Fully ripe.

The total weight of crop per acre is given in the following table in lbs. avoir. :—

	Total.	Dry Matter.	Water.
1st period .	6,358	1,284	5,074
2nd " .	10,603	...	...
3rd " .	16,523	4,383	12,240
4th " .	14,981	5,427	~~14,983~~
5th " .	10,622	6,886	3,736

From the first column we learn that the weight of the crop gradually increases up to the time of "Full Bloom," and then diminishes. The third column shows that the diminution of weight in the last periods is due to the plant losing a considerable amount of water, while from the second column it is seen that the dry organic matter continually increases up to the end of the plant's life. The accumulation of the dry organic matter is not however uniform, and is greatest when the plant is in full blossom.

The absolute quantities of carbon, hydrogen, oxygen, nitrogen, and ash in the dry Oat, are given in the following table in lbs. avoir. per acre :—

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
1st period .	593	80	455	46	110
3rd " .	2137	286	1575	122	263
4th " .	2600	343	2043	150	291
5th " .	3229	407	2713	167	372

Although, therefore, the absolute quantities of the various elements increase, yet the rate of increase is not uniform, or in other words, they are absorbed in different ratios in the different periods. The ratio of hydrogen to carbon, for example, gradually diminishes; while that of nitrogen to carbon decreases from infancy to bloom, at which latter period it increases very much for a short time,

during the early stages in the ripening of the seed, but falls again soon afterwards. The ratio of oxygen to carbon increases throughout the last three periods.

These researches show the period in the life of an Oat (which may be taken as an example of the annual cereals) at which it most requires any particular element of its food—for example, the greater part of the nitrogen is absorbed in the first three periods. In addition, they indicate the quantities of each of these elements removed from the land by the crop in question, and that the time of greatest activity for the assimilation of the elements, coincides with that of flowering.

CHAPTER IX.

REPRODUCTION.

THE processes by which new and independent plants are produced in nature are very varied, but they all agree in the fact that the new individual is always developed from a reproductive body, which is itself a portion of a pre-existing organism. The degree of complexity of this reproductive body varies very much: it may be only a single cell specially modified for this purpose, or it may be constructed of one or more cells which are not modified, and therefore do not differ from the ordinary cells of the plant.

The single cell specially modified for reproduction may be formed in one of two ways, either it may be the result of the coalescence of two masses of protoplasm and of their nuclei, as in the formation of the oosphere, which eventually becomes the embryo of a seed, or it may be a cell which is capable of developing into a new individual without the assistance of another cell.

The cell which is the result of the coalescence of two nucleated masses of protoplasm is said to be produced *Sexually*; and in contradistinction the single cell which by itself is capable of producing a new plant is said to be formed *Asexually*.

Plants which are merely produced from a portion of the body of their parent not essentially differing from it, are said to be produced *Vegetatively*.

The reproduction of plants then takes place, *Sexually*, *Asexually*, or *Vegetatively*.

Asexual reproduction is found very generally throughout the vegetable kingdom, but need not be considered in relation to Agricultural Botany.

In a previous chapter, in treating of fertilization, the process of **Sexual reproduction** has been described.

The plant developed in this manner commences a new generation, and being an independent individual, often has characters slightly differing from those of its parents. It is this natural tendency to variation which is taken advantage of in cultivation, to perpetuate such characters as are found to be most desirable for certain conditions, and to induce other useful variations by means of suitable crossings with other plants.

Hybridisation.—Fertilization can be readily effected between plants of the same species, and in some cases between closely allied plants of different species, the offspring in this latter case being known as a *hybrid.* The hybrid usually possesses some of the characters of each of its parents, and, so to say, stands between them; sometimes, however, it may present features more closely resembling one of its parents than the other.

In Nature hybrids are rarely found; for, as a rule, the greatest sexual affinity is possessed by individuals of the same species, and should the pollen from one plant be placed upon the stigma of another not of the same species, it would almost certainly be rendered useless by the principle of prepotency. Artificially, by transferring the pollen from anther to stigma, and protecting the stigma from any further reception of pollen, hybrids may be produced. The plants must however, be closely allied to

each other, or must possess the requisite degree of sexual affinity.

In a few cases distinct genera are capable of hybridising, but generally the degree of relationship must not be wider than that of species, and in this case some species are found to form hybrids readily, while others cannot do so. Varieties of the same species can generally hybridise, though this rule again is not without exceptions.

Further, although the pollen from one plant may fertilize the stigma of another one, it does not follow that this process can be reversed, and so instances are known in which "reciprocal hybridisation" cannot take place.

Hybrids are rarely fertile, in many instances absolutely sterile, between themselves; but, when crossed with one or other of the parent forms, offspring may be produced. These offspring more nearly resemble the parent form, and after repeated crossings the hybrids become undistinguishable from the original parent form.

Hybrids are often vegetatively more vigorous than their parents, as shown by the larger leaves and stems, and by a greater development of root-system. Their flowers too are often larger and more brightly coloured.

From an economic point of view the production of hybrids is advantageous in producing new and useful varieties of plants.

Vegetative reproduction is extremely common in Nature, and may be produced artificially.

Perhaps the simplest case is that of a Moss, in which new moss-plants may arise from branches which become separated by the decay of the connection with the stem on which they are borne.

Another instance a little more complicated, is found in

the production of Strawberries from runners, which differ from the moss-branch in being adapted for this purpose. The greatest adaptation occurs when special reproductive bodies are formed, such as the tubers of the Potato or Artichoke, or the bulbils of certain Lilies.

Runners.—Perhaps the most familiar example of a *Runner* is that of the Strawberry, which may be said to have two kinds of stems, the *long* and the *short*.

The *short stem*, although it may live for several years never becomes more than a few inches in height, owing to the fact that its internodes always remain undeveloped.

The leaves borne on these stems are the foliage leaves, which are necessarily always crowded together, and never removed much above the ground.

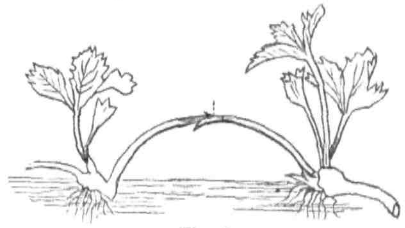


Fig. 36.
Runner of Strawberry (*Fragaria vesca*).

The short stem with its leaves constitutes the Strawberry plant proper.

The *long* stem arises as a branch in the axil of one of the foliage leaves on the short stem, and is characterised by its long and attenuated internodes. These long stems are the so-called *Runners*. The number of the lengthened internodes is two, or sometimes only one; the leaves borne at the nodes never develop into foliage leaves, but remain rudimentary, and are sometimes reduced to mere stipules.

The terminal internodes remain undeveloped, and on coming into contact with the soil, adventitious roots and foliage leaves are soon again formed, and thus a new Strawberry plant is produced.

Very often two or three plants are found connected together and apparently produced upon the same runner. This, however, is not the case, each plant being formed in the manner just described, at the end of its own runner, which is always an axillary branch from the plant immediately preceding it.

The runner often attains a considerable length, in order to place the young plant at a distance from its parent, to prevent any competition either for soil or air arising between them. It also affords a means of conveying nutriment from the parent to the offspring, and so persists until the latter has become fully established, after which it dies off, and the new plant becomes an independent individual.

Stolon is a name given to long creeping branches which bear leafy shoots and roots at the nodes. By the decay of the internodes the plants become free. Stolons are very frequently found among Grasses, some species spreading very rapidly by this means. Runners and Stolons are therefore practically the same.

Sucker.—In the Couch Grass another instance of vegetative reproduction may be studied. In this plant two kinds of stems are also to be distinguished, one aerial, and the other subterranean.

The *aerial stems* in many cases, besides the foliage leaves, bear the inflorescence; therefore the number of their internodes, and consequently their power of growth in length, is limited.

The *subterranean* stems, on the other hand, are capable of forming an unlimited number of internodes, and their growth in length proceeds whenever the necessary conditions are satisfied. The leaves borne on these stems

are mere scales, and serve to protect the growing point while forcing its way through the ground. At each node roots are formed, and also a bud, which may develop into an aerial stem, familiarly known as a *Sucker*.

The prevalence of the Couch Grass, and the difficulty in exterminating it, is due to this method of propagation, for a single node of a subterranean stem, even when detached, has the power of producing a new plant, and of putting forth fresh subterranean stems in all directions.

Similar examples are found in the *Offset* of the House-leek, the *Sucker* of the Mint, Rose, Plum, &c.

The **Tuber** of the Potato or Artichoke is similarly a reproductive stem, formed underground, and specially enlarged to contain the nutriment necessary for the first growth of the new plant.

In the axils of certain of the scale leaves of a Hyacinth, or Onion bulb (fig. 22), or the foliage leaves of some of the Lilies, small bulbs (bulbils) are formed. These bulbils when planted become new plants, and are again examples of vegetative reproduction.

Laying, *cuttings*, *grafts*, &c., are examples of the manner in which vegetative reproduction may be artificially induced.

Laying merely consists in the artificial production of a sucker, which is contrived by bending a branch and fastening it securely so that a small portion is in contact with the soil. Roots soon make their appearance at this point, and when sufficiently developed the connection with the parent is severed.

Cuttings.—Many plants are noted for the ease with which they may be propagated by removing a small portion and planting it. In the instances previously considered,

the young plant has been specially nourished by its parent until it can provide its own supplies, but in the cuttings this is not so. The portion employed must contain in its cells sufficient reserve material out of which to construct the members which are required to complete the plant. A very familiar example is the cutting of a Geranium, which has already stem and leaves, and readily produces roots. But even such a large portion as this is not necessary, a single leaf of some species of Begonias, &c., being capable of producing new plants.

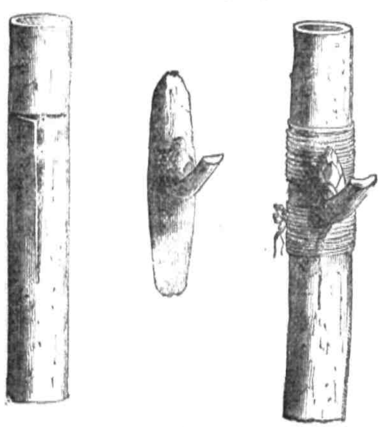


Fig. 37 (*from Figuier*).
The process of Budding.

Budding is another example of vegetative reproduction frequently practised by gardeners to propagate various kinds of Roses, &c. This process consists in removing a bud from one tree (the scion) and affixing it to another (the stock), in order that it may grow and become a branch upon the latter.

For this purpose a lateral bud (fig. 37, *B*) is cut from a shoot of the scion, together with a small portion of bark, ground tissue, and bast, any wood of the shoot which may be cut with it being carefully removed from the bud; this is readily effected, the thin walls of the cambium offering little resistance to the separation of the wood from the bast.

A T-shaped cut (fig. 37, *A*) as deep as the wood is made in the stock, and the tissues external to the wood raised for the reception of the bud. The bud is then inserted in this cut, and bound in securely though lightly (fig. 37, *C*). When the operation is successfully performed the cambium of the bud and the stock unite, and also the wood, bast, and ground tissues. The bud then receives supplies from the stock, developes as a branch upon it, and becomes an integral part of the whole.

Grafting, a process closely resembling budding, is performed by cutting a stock obliquely and fastening on to it a shoot cut also in an oblique direction, so that the cambiums, woods, basts, and ground tissues of the graft and stock are in contact with each other respectively. The graft and stock must be securely fastened together and the junction covered over to keep the cells in a turgid condition, and to prevent the access of the spores of any parasitic fungi which might gain an access to the plant at the wounded surface. The graft becomes a branch upon the stock, and eventually the two are one tree.

The advantages gained by this method are the invigoration of the graft by its union with the stock; and the production of flowers and fruit earlier than by the method of cuttings.

In all cases of vegetative reproduction, it must be borne in mind that the new plant is part of the substance of its parent, and in fact we must consider the various individuals which are vegetatively derived from the same parent as parts of it, and therefore belonging to the same plant. Whatever properties therefore are possessed by the parent, are found in all plants which are vegetatively derived from it. It is for this reason that vegetative propagation is so

commonly employed. The good qualities of Potatoes, Strawberries, &c., are handed down in the young plants raised in this way, and it is by this means that they can be most purely transmitted. Another advantage is that the young plant becomes useful much sooner than when raised from seed, and the time necessary for the early development is saved. A Geranium cutting, for example, blooms the next year, but a seedling Geranium does not bloom for one or two years.

On the other hand, if the method of vegetative reproduction is persisted in for too long a period, the plants are enfeebled by continued propagation in this way, they gradually lose their constitutional vigour, become weakened, and are much more likely to succumb to disease, or even to die out altogether.

It would appear that the protoplasm and nucleus by repeated division, lose their energy, become "worn out," and require a fresh stimulus. This required stimulus is gained by the process of sexual fertilization, from which results an entirely new cell. The oosphere is invigorated by fertilization, and the oospore invested with qualities never before possessed by any individuals. The plant derived from the oospore thus has properties entirely new, it starts with renewed vigour, and gives rise to a race much more healthy and more able to resist unfavourable conditions and disease.

This increased vitality lasts for a time, but sooner or later exhibits a perceptible diminution of power.

This is well seen in many fruit trees, in which deterioration has followed from continued propagation by buds, grafts, &c., but in no cases is it more apparent than in Potatoes. New varieties, supposed to be "disease proof,"

are continually being brought out: these have merely a stronger constitution through being raised from seed, and in a few years it is found that they again deteriorate and are liable to fall a prey to disease.

The two methods of sexual and vegetative propagation may, in this manner, each serve to complement the other; it is through the former that new varieties can be obtained, and by the latter that they can be perpetuated.

CHAPTER X.

DISEASES.

THE question of the health of a plant, and the best way of securing it, is of paramount importance, upon it altogether depending successful cultivation; and it is only by a thorough knowledge of plant physiology that conditions favourable or unfavourable can be understood, and the latter modified or guarded against.

Adverse conditions may be permanent, in which case it is obvious that no good results can be obtained; but they may be merely temporary, under which circumstances, if not too prolonged, little loss would be experienced were it not for the fact that the vigour of the plant is impaired, and it is thereby rendered more liable to succumb to attacks of fungi which in the perfectly healthy state it would successfully resist. The destruction caused to crops by fungi is enormous. In the present chapter we will briefly discuss the nature of these fungi, the general conditions of fungus life and their methods of reproduction, and will then treat of a few of the more important of the fungoid diseases.

The plants which we have hitherto been considering are able to manufacture the necessary organic compounds from certain inorganic ones. But all plants have not this power, and a large section, having no chlorophyll, are directly, or

indirectly, dependent on those possessing it. Some of the plants devoid of chlorophyll prey on living organisms, and are called *parasites;* while others obtain their supplies from dead organic matter, and are known as *saprophytes.* We need here only consider one or two of those parasites which, by drawing their supplies from cultivated plants, cause a loss to the cultivator.

The most lowly organized plants may be either unicellular or multicellular; but the cells are not differentiated into the three tissue systems, and as a consequence these plants have not the three members—stem, leaf and root. The name given to this group is that of *Thallophytes.* The Thallophytes very naturally are divided into two groups, those which possess chlorophyll (Algæ), and those which do not (Fungi). It is only with one or two forms of the latter that we have to deal. It must not, however, be supposed that all non-green plants are fungi: on the contrary, not a few forms are found among the highest group of plants, which, having no chlorophyll, are dependent on other plants. One of these—the Dodder—a plant closely related to the Convolvulus, preys upon Clovers, often causing great loss to the farmer.

In ordinary parlance the term Fungus is applied simply to Mushrooms and Toadstools, but, according to our definition, it includes in addition to these, the moulds, mildews, and very many other parasitic or saprophytic forms. In considering a fungus we must never lose sight of the fact that it belongs to the vegetable world, and is subject to the ordinary conditions of plant life: its optimum temperature, however, is often considerably lower than that of the higher plants, a fact which is of considerable importance in some fungoid diseases. The cells are essentially the

same as those of the higher plants, having cell-wall, protoplasm, and sap-cavities. Generally they are much longer than broad, and, when viewed through the microscope, resemble threads, so have been designated by the Greek word *hypha*, which means a thread. A hypha, then, is a filament made up of one or more long cylindrical cells. These cells branch and rebranch in all directions to form a felted mass, which is described by a term derived from the Greek word for fungus—*mycelium*.

Reproduction.—The fungus can reproduce either vegetatively, sexually, or asexually.

In the *asexual* method special cells are formed, which have the property of growing into new fungi. These cells are often produced in very great numbers, and are the chief means by which disease is spread; they are formed either by the division of one cell, or are budded off from the extremity of a special hypha, and are usually termed *spores*, *sporidia*, or *conidia*.

Sexual reproduction is only known in certain fungi. A union of two cells takes place—but the details of the process are often complicated, and must be studied in each particular case.

The parasitical fungi penetrate the tissues of the host-plant, their mode of action being to push the hyphæ along the intercellular spaces, and also to bore through the cell-walls. Once inside the cell, the hypha succeeds in killing the protoplasm, devouring it and the useful cell-contents; and thus gaining fresh vigour from every cell which is overcome, it permeates and destroys cell after cell, until the usefulness of the host-plant is impaired, or it may be altogether destroyed. If this destruction were confined to a few cells, or even to a few plants, the loss would be

trifling; but the extraordinary rapidity with which the fungi multiply, and the ease with which their reproductive bodies are carried from plant to plant, renders their extirpation a very difficult matter, and occasions most serious losses.

Finger and Toe. — Finger and Toe, Club-root, or Anbury, is the name given in various parts of the country to the disease which attacks the roots of Turnips, Cabbages, and in fact nearly all Cruciferous plants, the term "Club" being specially applied to the diseased Cabbage roots. It is exceedingly widespread, occurring in many countries of Europe, and in N. America.

The first symptoms of the disease are tumorous swellings on the roots, to be afterwards followed by complete rottenness. To understand the nature and cause of this disease, we must examine and compare the healthy and diseased tissues. The healthy root has been described (ch. iii.). Quite different in appearance (fig. 38) is that of a root suffering from "Fingers and Toes." A careful comparison of sections, taken from roots of nearly the same age, leads to the conclusion that the number of cells is much greater in the diseased than in the healthy root, the arrangement of the fibro-vascular bundles is also disturbed, and many cells are conspicuous by their much larger size. The swellings on these roots are due to the excessive enlargement of many of these *giant cells*. The cause of these abnormal conditions must next receive our attention.

Referring again to our figure, the giant cells are seen to be further remarkable, by containing an opaque mass of protoplasm. Numerous granules and drops of oil are embedded in this mass of protoplasm; in some stages it contains numerous vacuoles, in others it is fairly dense.

This is not the original protoplasm of the cells, but belongs to an organism living inside the cells of the diseased root, and in this condition consisting of a single mass of protoplasm destitute of cell-wall. This organism is known by

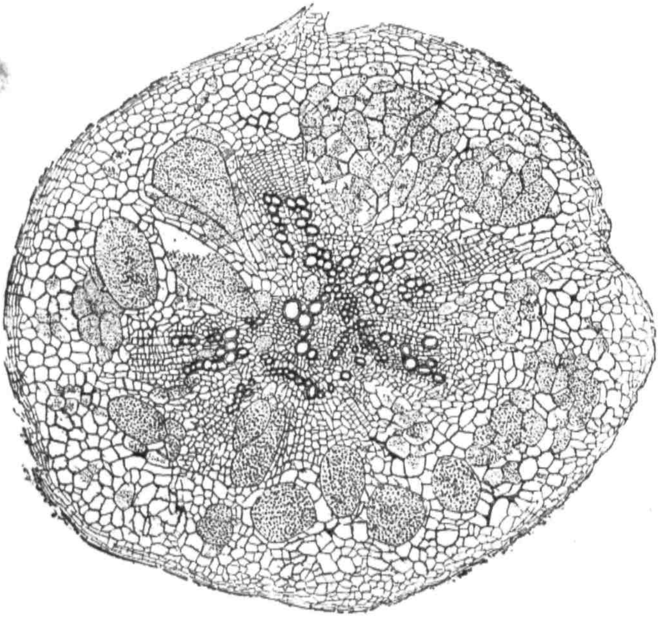


Fig. 38 (*from Ward, after Woronin*).

Transverse section of a root attacked by *Plasmodiophora*. Numerous giant-cells are seen full of granular protoplasm and young spores: the enlarged cells disturb the arrangement of the other tissues.

the name of *Plasmodiophora brassicæ*: it is not one of the true fungi, but belongs to a lower group known as *Slime-fungi*. Sometimes the cell-protoplasm can be detected in these cells as well as that of the Plasmodiophora.

The protoplasm of Plasmodiophora has essentially the same properties as any other cell. It is automatic, and may be seen slowly moving inside its host's cell.

It is also metabolic, but cannot manufacture its own supplies, deriving them from those destined to nourish its host. When a small portion enters a previously healthy cell, a battle immediately commences between these two masses of protoplasm. The plant, striving for the mastery, sends down large supplies to the assistance of the attacked cell, which gradually enlarges and becomes a giant cell in consequence of this extra supply; while the Plasmodiophora, for its part, first devours the cell-protoplasm, and then the food substances which are being conveyed to the cell.

It is reproductive, first, by the process of division. Small portions are separated, which, passing through the minute pits in the cell-wall, enter another cell with the same disastrous effect as before, and in this way the disease spreads throughout the root. Secondly, when the Plasmodiophora has finished its existence in any cell, it breaks up into an enormous number of small spherical cells—spores — about one fifteen-thousandth of an inch in diameter (fig. 39). The fate of these spores is very interesting, and affords a clue to the spread of this disease.

The Turnip or Cabbage root, when its cells are dead, becomes soft and rotten, and the putrid mass contains millions of these spores, which, under favourable conditions of temperature and moisture, and with a supply of air, germinate—that is, the cell-wall is ruptured and the protoplasm escapes (fig. 40). The minute mass of living protoplasm, destitute of cell-wall, frequently changes its shape, and by means of the motion of a fine whip-like

prolongation — *cilium* — can insinuate itself between the particles of soil. It does not long continue in this state, but withdrawing the cilium, moves by merely creeping over the particles of soil, and at this stage may effect an entrance into the roots of Cruciferous plants, and so penetrate the cells, and commence the disease.

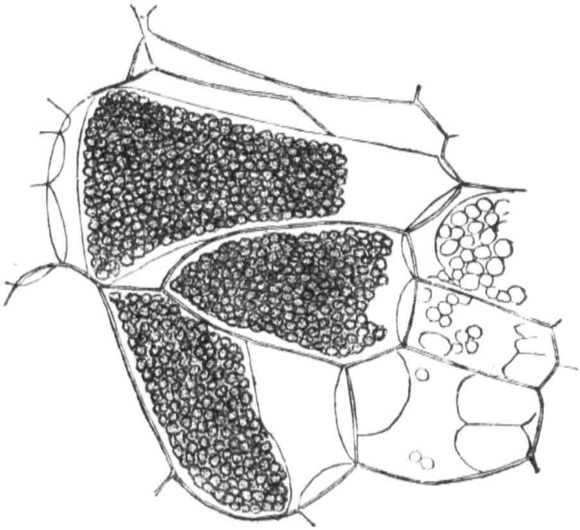


Fig. 39 (*from Ward, after Woronin*).

Giant-cells more highly magnified. In the three on the left the *Plasmodiophora* has broken up into very numerous spores.

Observations are still wanting to show the actual entrance of this fungus into the Turnip or Cabbage root, but the evidence seems to point to the fact that the entrance is effected through the root-hairs. Once inside the plant the disease is soon established, and quickly spreads throughout its tissues.

From the foregoing sketch of the life of this remarkable fungus, it is well seen that to prevent the continuance of this disease the fungus must be killed. To leave the decayed roots to rot in the ground, or to throw them on manure heaps, is simply a method of spreading it. These rotten roots should in all cases be most carefully destroyed. To burn them is no doubt the most effectual way of

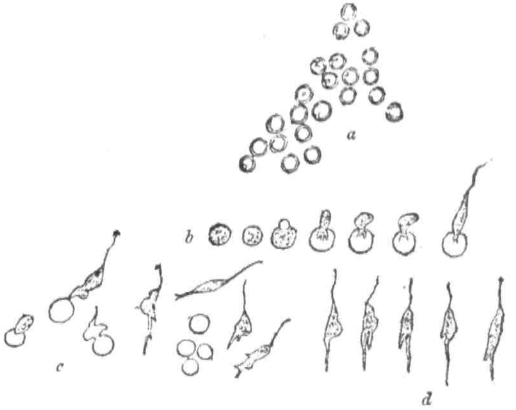


Fig. 40 (*from Wood, after Woronin*).

Spores of *Plasmodiophora Brassicæ*, showing various stages of elimination. The spore (*a*) bursts as one point (*b*), and the protoplasmic contents emerge as a ciliated, naked mass of protoplasm (*b*, *c*, *d*), which creeps about by continually changing its form (*d*). Very highly magnified.

eradicating the disease, but is perhaps hardly a practical suggestion in this case. The fungus when in the soil can be killed by the application of various poisons. With this object Gas-lime and Lime are often recommended. These should be liberally applied while the diseased Turnips, and therefore the Plasmodiophora spores, are on the surface of the ground, and before they are buried and thus to a great

extent protected. These substances are destructive to all life, and seeds, therefore, must not be sown until the poisonous effect has disappeared from the soil.

Plasmodiophora brassicæ, although it attacks many of the Cruciferous tribe, is fortunately powerless to injure any plants not members of the group. By growing other crops upon infected land, the fungus must gradually be exhausted and finally disappear from sheer starvation. To effect a cure by this means, Charlock and all Cruciferous weeds must of course be destroyed, not only on the land itself, but even in the hedgerows, for they would only serve as a means of propagating the disease.

Cruciferous plants, in common with all cultivated plants, are liable to the attacks of Insects, especially in the larval stage. These larvæ often cause swellings on the roots which to a certain extent resemble "Finger and Toe," but which on no account must be confounded with it. The confusion has no doubt arisen from the presence of larvæ in the roots infested with Plasmodiophora, especially in the rotten condition; but the Insect attack does not exhibit the disturbed arrangement of tissue we have described, and it may clearly be distinguished from the fungus attack, certainly with the microscope if not with the naked eye.

Potato Disease.—The appearance of the "Potato disease" is too well known to need a lengthened description. When the Potatoes are dug up, some are found to have one or more large brown patches, caused, as is easily seen, on scraping the Potato, by the discoloration of its cells; others may be completely rotten, and observation shows that the brown spots are only an early stage of this advanced condition. We have now to inquire into the cause of the discoloration and subsequent rottenness.

A section cut to include some of the diseased, and some of the still healthy cells of a diseased Potato, and placed under the microscope, shows that some of the cell-walls have turned brown, and that their protoplasm is dead and of a similar colour. In addition, numerous thread-like bodies are found among the brown cells. With a tolerably high magnification it is seen that these threads are long, cylindrical cells joined end to end, each with its own cell-wall and protoplasm. They are in fact, the hyphæ of a fungus (*Phytophthora infestans*) which branches freely throughout the diseased portion, causing the destruction of the cells which it enters, until the whole tuber is decayed.

The fungus, when it has found a home in a Potato, does not always immediately commence its work of destruction. Should it first attack the tuber late in the season, about the time that the haulms are dying down—that is, at the close of the period of active vegetation—it may remain dormant for some time. The dormant fungus hypha is very small, and easily escapes detection: it occurs in minute brown specks just beneath the epidermis, which are easily overlooked, and this explains why Potatoes, when first dug up, are often apparently sound. During the winter, however, the Potatoes should be looked over several times to find any which are beginning to decay, or in other words, those in which the fungus hyphæ, instead of remaining dormant until spring, commence an active existence in the tubers.

The Potato sets, when planted in the spring, resume their active growth, and should they be infected with the fungus, it also commences a period of activity, its hyphæ penetrating and destroying the cells of young, growing plants (fig. 41). Many young stems succumb altogether from this

cause; in others, the fungus keeps pace with the growth of the stem, and entering the leaves, produces the brown and black patches which may be observed in the Potato leaves during the summer months. When observed in large numbers, it is a sure sign that many Potatoes will be found diseased.

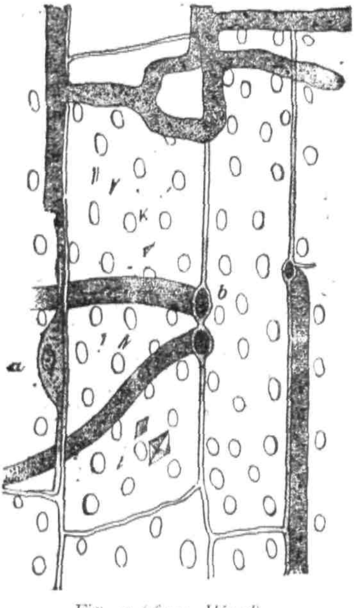


Fig. 41 (*from Ward*).
Cells from the stem of a Potato, with the hyphæ of *Phytophthora* running in the cell-walls; *a*, a nucleus.

The cause of the spots cannot be determined by the unaided eye, but when sections transverse to the leaf and through the margin of one of the patches (fig. 42) are examined by the microscope, it is found that their cells are dead, and that their dark colour is due to the discoloration of the cell-walls, the protoplasm, and cell-contents. The contrast between these and the living turgid cell, with its bright green chlorophyll corpuscles is very striking. But this is not all that may be observed. Numerous hyphæ are also found between the cells in the many intercellular spaces, and others are seen projecting into the air. The hyphæ in the tissues of the leaf ramify in the intercellular spaces, which they block up, and thus deprive the cells of

their needful supply of air; they also penetrate the cells, absorbing the products of manufacture, and ultimately destroying them. The structure and function of the leaf

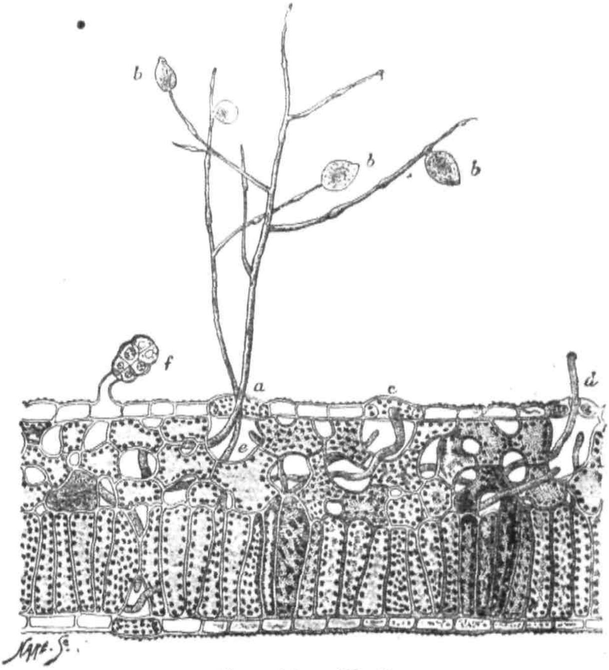


Fig. 42 (*from Ward*).

Transverse section of a Potato leaf through the margin of a diseased spot. Numerous hyphæ are seen in the tissues of the leaf, some of which emerge through the stoma (*a*, *c*, *d*) and bear conidia (*b*); at the darker spots the cells are already destroyed; *f*, a hair. *The leaf is inverted, the lower surface being placed uppermost.*

having been fully dealt with in a previous chapter, it will be understood how the destruction of any of its cells injures the leaf by depriving it of the means of assimilation,

and thus lessening its utility; and when the hyphæ spread from cell to cell, rapidly increasing the area of their work, the measure of the harm which is wrought will readily be appreciated. At the close of the life of the leaf some hyphæ work their way along the leaf stalk and down the haulms to the tubers, which they enter, some of the hyphæ remaining in the tuber in a resting state until such time as the conditions are again favourable for development.

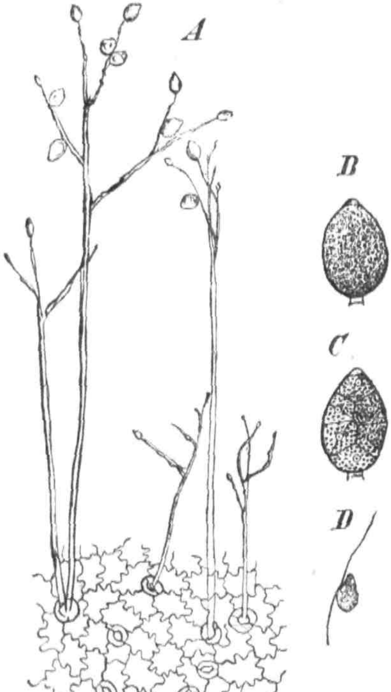


Fig. 43 (*from Strasburger*).

A, Lower epidermis of Potato with aerial hyphæ emerging from the stoma and bearing conidia; *B*, a conidium; *C*, conidium with divided contents; *D*, a zoospore.

As soon as the hyphæ in the leaf have gained sufficient strength, special aerial hyphæ are produced, which emerge through the stoma (fig. 43), branch freely, and bear ovoid reproductive bodies known as *conidia*. The conidia are liberated from their hyphæ, and being exceedingly light, are scattered in all directions by gusts of wind. When

placed in a drop of water, or on any moist surface, the protoplasm of the conidia undergoes division (fig. 44, *b*), and from the pointed end (*c*), about ten minute masses of protoplasm (*zoospores*) emerge. These are each provided with two cilia (*e*), by the motions of which they swim about freely for a short time; afterwards they withdraw the cilia and surround themselves with a cell-wall, and then emit a delicate tube (germ-

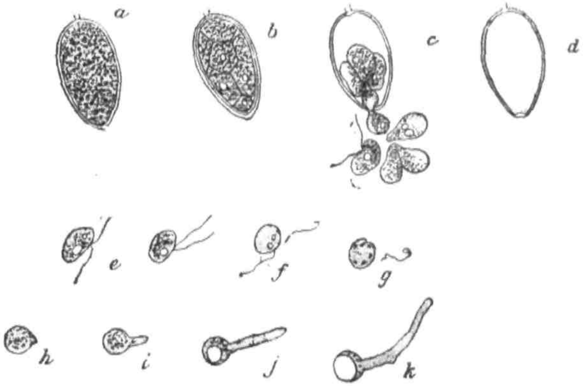


Fig. 44 (*from Ward*).

Germination of a conidium of *Phytophthora*. *a*, mature conidium; *b*, its protoplasmic contents becoming divided; *c*, the escape of the zoospores; *e*, *f*, zoospores with two cilia; *i*—*k*, germination of zoospore and formation of its germ-tube (*k*).

tube, (*k*). If the zoospore should not fall on a Potato leaf its development proceeds no further, and thousands upon thousands must perish in this manner; but on the Potato leaf the extremity of the germ tube secretes a ferment by which it is enabled to bore a minute hole through the wall of an epidermal cell (fig. 45, *c*), and thus effect an entrance into the leaf, or it may pass in through a stoma (*a*).

It is then by means of the conidia and zoospores that the disease is communicated from plant to plant; but all conidia which fail to fall on leaves are not lost, for it also appears that many of these minute bodies are washed into the soil by the rain and are able to penetrate the tubers and infect them with disease.

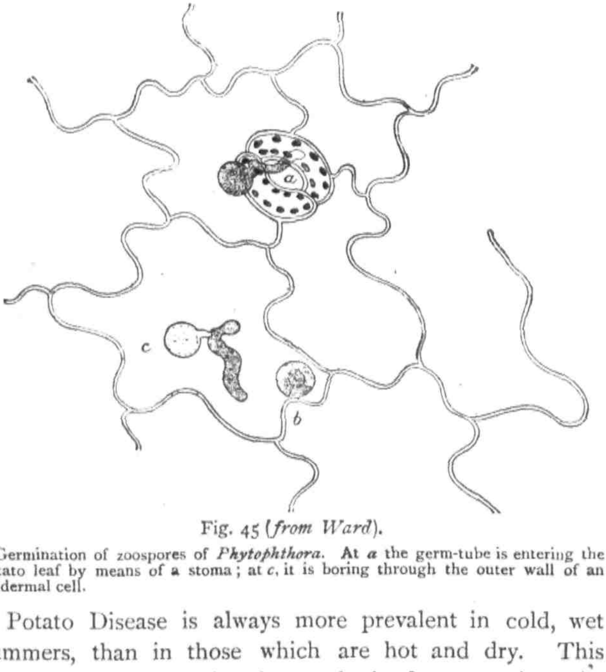


Fig. 45 (*from Ward*).

Germination of zoospores of ***Phytophthora***. At *a* the germ-tube is entering the potato leaf by means of a stoma; at *c*, it is boring through the outer wall of an epidermal cell.

Potato Disease is always more prevalent in cold, wet summers, than in those which are hot and dry. This is readily explained by the method of propagation, the conidia requiring moisture for their germination. But a cold, wet season is not without effect upon the Potato plant itself, enfeebling its vitality in no inconsiderable

degree, by decreasing the transpiration, and thus allowing water to accumulate and saturate the leaves. As a consequence, the cell-walls become softened, and the germ-tubes then find a more easy entrance. In a hot and dry summer the epidermal walls are too hard for the germ-tube to bore through, and many of the conidia must be shrivelled up and perish. Cold temperature too, is against the Potato, which has a fairly high optimum; but it is most favourable to the fungus, which flourishes best in a much lower temperature.

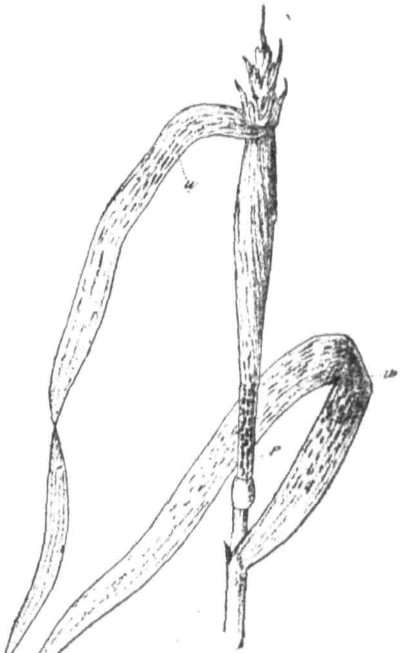


Fig. 46 (*from Ward*).

Young plant of Wheat infested with "Rust." *u*, Summer-spores; *p*, Winter-spores.

The only real remedy for Potato disease is to thoroughly stamp out the fungus. All the leaves, haulms, and especially rotten Potatoes should therefore be burnt; to leave these on the land or to throw them on manure heaps is certainly to ensure the spread of the disease. Lately an

attempt has been made to kill the conidia or zoospores, without injuring the potato plants. A mixture known as the *Bouillie Bordelaise*—20 lbs. of sulphate of copper dissolved in 100 gallons of water; and 10 lbs. of freshly slaked slime, stirred, when cold, into the copper solution—is applied to the leaves in a fine spray. The results of numerous experiments with this mixture, show that it has some effect in checking the disease, and that a gain in the weight of the tubers follows its use.*

Rust of Wheat.—The parasitic fungus which causes the well-known yellow or yellowish-red lines and patches upon the leaves of Wheat (fig. 46 *u*), and the black lines upon the straw, belongs to a group of fungi which are able to prey upon more than one kind of plant, and to assume different forms in their separate hosts. The forms adopted are so diverse that special names have been given to them, and it is only quite recently that we have been in possession of their complete life-history.

The fungus which causes the "Rust of Wheat" (*Puccinia graminis*) lives in the early spring upon the common Barberry, and in the summer on the Wheat, and passes the winter in the form of spores specially adapted for this purpose. We commence our study of this interesting fungus with its appearance on the Barberry.

Very often, in the months of May or June, numerous orange spots may be observed on the leaves of the Barberry, sometimes more than one on a leaf. These spots are generally circular, and where they occur, the leaf is swollen to twice or thrice its usual thickness (fig. 47, *I*), the swelling protruding chiefly on the lower surface. To

* Report on recent experiments in checking Potato Disease; Board of Agriculture.

understand the diseased condition of these leaves, thin sections must be cut transverse to the leaf: their

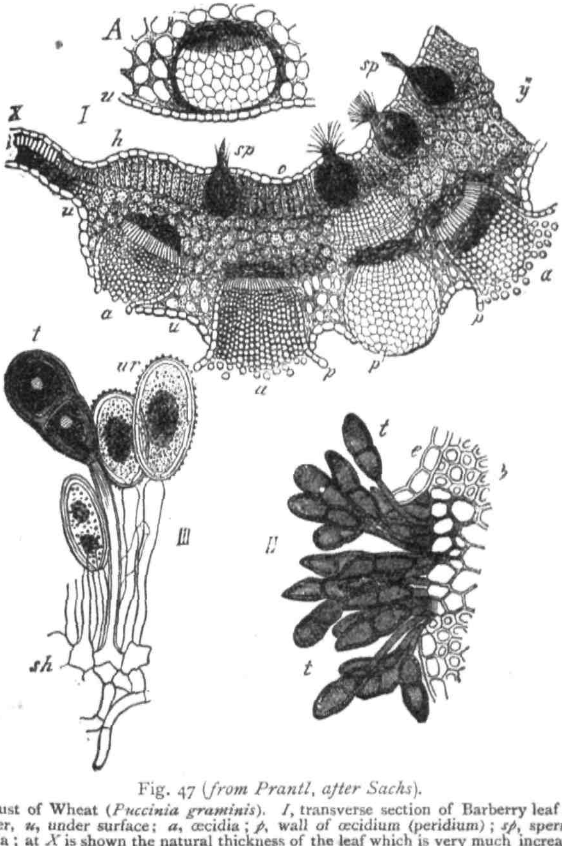


Fig. 47 (*from Prantl, after Sachs*).

Rust of Wheat (*Puccinia graminis*). *I*, transverse section of Barberry leaf; *o*, upper, *u*, under surface; *a*, œcidia; *p*, wall of œcidium (peridium); *sp*, spermogonia; at *X* is shown the natural thickness of the leaf which is very much increased from *u* to *y*. *A*, a young aecidium. *II*, Winter-spores (*t*) on the Wheat. *III*, Summer-spores (*ur*), and Winter-spores (*t*) on the Wheat.

appearance is shown in fig. 47, *I*. On the left hand side

of this figure (*X—h*) the normal, healthy condition of the leaf is shown, with its upper and lower epidermis, the palisade and spongy tissues; but on the right, a serious disturbance is noticed in the spongy tissues, whose cells have increased both in size and number. The most conspicuous objects in the section are the large open cups (fig. 47, *I a*) with numerous small spherical cells escaping from their mouths. These cups are known as "cluster-cups" or *æcidia*, and the spores developed in them may be conveniently termed "spring-spores" (*æcidio-spores*). Between the cells of the spongy tissue, numerous fungus hyphæ are found closely felted together.

We must leave the account of the entrance of the fungus into this leaf until its connection with the Wheat has been fully dealt with. The spring-spores emitted from the œcidia are unicellular, spherical, or polygonal, and strange to say, have not the power of infecting the Barberry, but find a suitable home on the Wheat.

For a long time the belief was entertained that Barberry bushes were inimical to the Wheat, as Rust was found to be much more plentiful on Wheat which grew in the neighbourhood of the bushes having orange spots on their leaves; and although no active measures were taken in this country to uproot the Barberry, in the State of Massachusetts the "Barberry law" was enacted, compelling every farmer to destroy the Barberries, and inflicting penalties for non-compliance with the law. Opinions on this point were by no means unanimous, some maintaining that there was a connection between the yellow spots on the Barberry and the Rust on the Wheat, whilst by many this was regarded as a mere superstition. It was not till about 1864 that Prof. De Bary cleared up the mystery.

The spring-spores are found to germinate readily on the leaves of Wheat, emitting a small germinal tube, which enters the Wheat leaf through one of the numerous stoma. It then branches freely between the leaf cells, destroying them and absorbing their contents. The first outward sign of the disease is the appearance of a small, yellow spot which gradually increases and assumes a rusty colour, as the hyphæ extend their ramifications. Soon

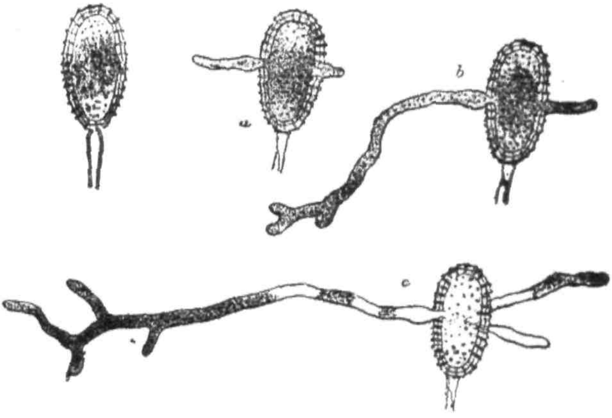


Fig. 48 (*from Ward*).
Summer-spores of *Puccinia graminis* germinating. *a*, *b*, *c*, Successive stages in the formation of the germ-tube.

a compact mass of these hyphæ is formed beneath the epidermis, and at their free ends a number of spores are formed, which are set free by the rupture of the epidermis, and are succeeded by others as soon as they are detached. These spores (*Uredo-spores*) (fig. 47, *III*) are ovoid and of a yellow colour; they are produced in large numbers on the leaves of Wheat during

the summer, and may fitly be termed "Summer-spores." They germinate on the Wheat. Germinal tubes (fig. 48) are protruded, which enter a Wheat leaf through a stoma, with the same result as already described. In this way the Rust is quickly spread from one Wheat plant to another. But towards autumn, when the Wheat is about to be cut, another kind of spore makes its appearance,—the "Winter-spore" (fig. 47, *II*), often known as *Teleuto-spore*. These winter-spores are developed at the same spots and from the same mycelium as the summer-spores, but are easily distinguished from them by being united in pairs (fig. 47, *II*) and by their much darker colour and thicker walls. These spores, produced at the end of the year, must rest through the winter, and the thicker cell-wall serves as a means of protection during this period. At the return of spring the Barberry puts forth its new leaves, and the winter-spores in the Wheat about the same time commence to germinate. This process consists in the emission of a hypha (fig. 49, *a*)—often termed a *promycelium*—which, unlike the other cases considered, has not the power of entering a plant; but on it are borne a number of small spores—*sporidia*—which, if placed on a Barberry leaf, secrete a ferment (acting on the cellulose), and are by this means enabled to pierce the outer wall of the epidermal cells. The fungus in the Barberry leaf now attacks the cells, spreading on all sides; soon the characteristic yellow spots appear, and, a little later, the cluster-cups and the spring-spores. The latter, blown in all directions, carry the disease to any Wheat plant they may chance to find, and the disease is rapidly disseminated.

In estimating the extent of the damage done by Rust of

Wheat, we must consider the various points of attack. The injury is of a two-fold character—first, as affecting the leaves; and secondly, the straw.

In the leaves, the cells containing chlorophyll are attacked, destroyed, and any products in them absorbed.

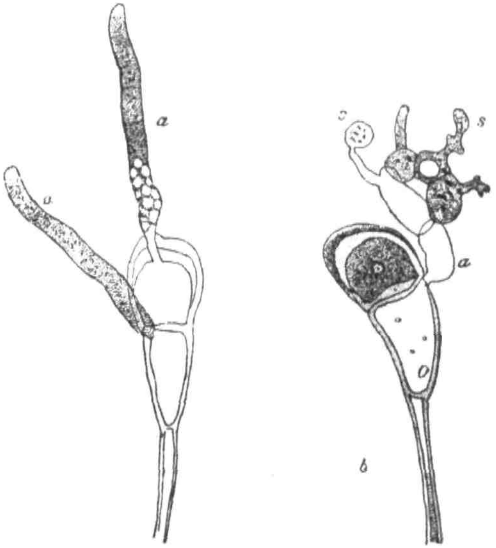


Fig. 49 (*from Ward*).

Germination of the Winter-spore of *Puccinia graminis*. In the left-hand figure each cell has developed a promycelium (*a*); in the figure on the right the lower cell only has germinated, its promycelium producing sporidia (*s*).

With the death of each chlorophyll-bearing cell, the plant loses a manufacturing element, and when nearly all the cells of a leaf are destroyed, the plant suffers considerably, through a diminution of the supplies which were intended to be utilized in furthering the development of new

members, or to be stored up as reserve material in the grain.

In the straw, too, the same destruction of manufacturing cells takes place, and the supplies on their way to the grain may be diverted and appropriated by the fungus.

Fortunately, the winter-spores have no poisonous qualities, and their presence in chaff is of little consequence; the injurious effect of the fungus, therefore, is chiefly felt in the inferiority of the grain.

Ergot.—In the autumn the Cereals and very many Grasses, such as Rye-grass, Fescues, &c., may be found with purple bodies projecting from the spikelets. These purple bodies—Ergots—are a little thicker than the natural grains, and vary in length from about ½ an inch to nearly twice that length. They are found, on microscopical examination, to be a number of hyphæ felted together into a hard mass, the outer hyphæ being coloured and affording protection to the inner, more delicate, white ones, which contain a large supply of reserve material. These hyphæ belong to a fungus known as *Claviceps purpurea*, and the ergots are merely a special resting condition of this fungus adapted for passing the winter. Such collections of hyphæ, forming a hard body capable of hibernation, are not uncommon, and are generally designated *Sclerotia*.

The ergot is a very convenient starting point from which to trace the life-history of the fungus.

After remaining quiescent through the winter, the ergot commences its germination by the formation of several small "heads," which soon grow into short, thick stalks (fig. 50, *cl*), with spherical nobs on their summits (*stroma*) (*D*). From a section of one of these nobs (*E*) we learn that it is a mass of hyphæ, with numerous cavities—termed

perithecia—arranged round its circumference, each of which opens by a minute aperture (*cp*) into the air. When subjected to greater magnification, each perithecium is seen to contain a number of long, club-shaped cells, which are named *asci*. In each ascus, eight long spores (*sp*) (*ascospores*) are produced by the division of the contents of the ascus. The spores are liberated during the early part of the summer, at the time when Grasses are in flower. As they are easily scattered in the air, some few will certainly fall on Grass flowers, and their peculiar, elongated shape seems eminently adapted to enable them to penetrate between the various parts of one of the flowers and lodge at the base of the pistil. A germinal tube is then protruded, which enters the tissues just below the ovary. After a short time, numerous colourless hyphæ—the *sphacelia*—emerge just beneath the ovary, and commence to bud off conidia from their extremities (fig. 51 *F*). These conidia, when carried to other flowers, are also able to infect them. They are chiefly transported by insects,

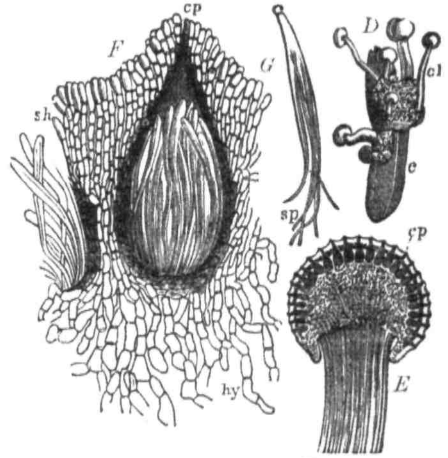


Fig. 50 (*from Krafft, after Tulasne*).
G, Germination of sclerotium; *E*, section of stroma with perithecia; *F*, section of perithecium with asci; *G*, ascus with ascospores (*sp*).

which are tempted to visit these infected flowers to procure a sweet fluid secreted in them. The conidia become entangled on the legs and probosces of the insects, and are thus carried from flower to flower.

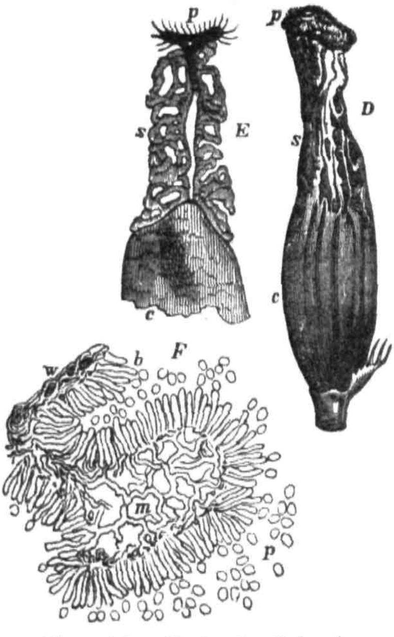


Fig. 51 (*from Krafft, after Tulasne*).
Ergot (*Claviceps purpurea*). *D* and *E*, grains of Rye infected with Ergot; *c*, the young sclerotium; *s*, the sphacelia. *F*, section of sphacelia; *b*, hyphæ from which the conidia (*p*) are abstricted.

At the close of summer, when the grain should be ripening and special supplies are transmitted to it, these are appropriated by the fungus and employed in the formation of the ergot. The ergot is formed just beneath the sphacelia, which remains above with the withered pistil (*p*) at the top of all.

The ergots are endowed with such poisonous qualities that when, either by accident or in times of scarcity and famine, they are mixed with sound grain for human food, the consequences are most serious, and appalling disease is produced. It is generally supposed also that the ergots eaten by stock have a very injurious effect upon them, but doubts of this have lately been entertained.

Smut.—Perhaps one of the most conspicuous of plant diseases is that commonly known as "Smut," a name which fitly describes the condition of an infected ear of Barley or Oats, the grain having all the appearance of a mere mass of black powder. This black powder is simply the spores of a fungus known as *Ustilago segetum.* The spores are set free from the plants attacked just before the corn is ripe, they are exceedingly minute (25,000,000 to a square inch), and are very easily distributed. The spores themselves are incapable of infecting other plants, but on germination (which takes place readily in water or on a moist substratum), they emit a small germinal tube which divides into one or two cells by means of transverse partitions, and from it a few spherical cells—*sporidia*—are budded. These sporidia, by protruding a fine germinal tube, may effect an entrance into very young plants, but it is only just when the grain has germinated and before the first leaf has appeared above ground, and while therefore the epidermal cells are very tender and unthickened, that the germinal tube is able to bore through the external tissues.

Should the spores be introduced into a nutritive solution, such as might be found in a manure heap, their germination proceeds in a somewhat different manner to that already described in water. In this case the spore first gives rise to the germinal tube and sporidia as before, but afterwards the sporidia bud and produce cells known as *conidia*; these bud again and again, until in a short time the whole manure heap becomes infested with them. Manure may thus be the means of introducing millions upon millions of these conidia into the soil, where they may find the opportunity of infecting the young germinating plants. The safety of the crops lies in the fact that they

are only vulnerable in one point, just where the first leaf springs from the stem, and then only for a short time, the cell-walls very soon becoming too hard to be penetrated by the germinal tubes. The fungus, once inside, grows and keeps pace with the growth of its host, without, however, causing any serious disturbance of its tissues, and its presence may be altogether unsuspected until the time of flowering, when the fungus, taking possession of the supplies intended for the ripening grain, utilizes them for the production of its spores, and the full mischief becomes apparent. This disease, it is well known, may be checked by steeping the grains in a solution of copper-sulphate, this solution killing the spores, whilst it is harmless to the hard, tough testa of the grain, unless the immersion be too prolonged.

Our space only permits us to study the life-histories of a few important disease-causing fungi. The consideration of some of these, however, notably "Finger and Toe" and "Potato Disease," has been sufficient to enable us to thoroughly grasp the nature of fungi, their methods of attack and their disastrous effect on the plants. These forms may be regarded as typical of other parasitical fungi, such as — various species of *Pythium*, which attacks seedlings just emerging from the ground, and causes the phenomenon of "Damping off"; *Exoascus pruni*, which attacks Plums, and is the cause of "Pocket Plums"; *Podosphæra castagnei*, which is the mildew of Hop; and *Tilletia carries*, the Bunt of Wheat — to these we need only thus briefly refer.

CHAPTER XI.

GRASSES.

In any work on economic botany the Grasses must always have great prominence, constituting as they do perhaps the most useful family of plants into which the vegetable kingdom is divided. They are very widely distributed, flourish in almost every climate, and have been cultivated from such early times that the origin of some of the cereals is quite lost in obscurity. Providing the staple food of many races of men, and supplying various other requirements, the Grasses are necessarily of the utmost importance in agriculture. Roughly speaking, for our present purpose they may be classed as those which provide grain—the Cereals; and those useful as hay or fodder—the pasture Grasses.

In treating this important family it will be convenient to study the members of the plants separately, and then to consider in detail a few of the more useful kinds.

Root.—Roots in general have been fully dealt with in Chapter III., and only a few points of special importance to the family of Grasses remain to be considered.

The root-system of anyone of the Grasses, when pulled up, will be found to consist of a number of fibre-like roots, which are of nearly equal diameter throughout their whole length, and hence are described as *fibrous*,—in other words, these roots have no power of increasing in thickness.

Their diameter will be found to vary from $\frac{1}{4}$ to $\frac{1}{100}$th of an inch.

It is a matter of no little difficulty to extract the entire root-system of any plant from the ground, and it can only be done by most carefully washing away the numerous particles of soil. In digging or pulling up a plant, a very poor idea of the mass of roots is obtained, so many, especially of the smaller ones, being broken off or destroyed. To obtain a fairly accurate conception of the length, distribution, or depth of the root system, plants have been grown in special boxes or pots, and the soil removed by washing; trenches have also been dug in the ground 6 or 7 feet deep, and the earth washed away from the roots.

By these methods the roots may be exposed, and the depth to which they penetrate measured. Thus Schubart traced the roots of a plant of Winter Wheat as deep as 7 feet, though the average depth of our cereals appears to be about 4 feet. According to Fraas, however, the roots of the Wheat never penetrate deeper than 18–24 inches. Treated in the manner described, the root-system is found to be composed of several roots springing directly from the base of the stem, these spread on all sides, and give off numerous offshoots, which in their turn branch again and again until the ground is penetrated in all directions. The various roots, if separated, and placed end to end, would stretch for a very considerable distance. In the case of the Oat and Barley, this length has been measured by Hellriegel, and estimated to be in the former case about 150 feet, and in the latter about 132. Nobbe has found the length of the Wheat roots to be 568 yards. These figures convey some idea of the extensive area from which

any one of these plants may draw its supplies, stretching out in every direction far and wide in search of food.

The proportion which the root-system bears to the whole plant will vary with its age. We have seen that the root is the first member to emerge, and for a time its further devolopment keeps ahead of that of the stem and leaves, and so at the end of April, the root-system of a plant of Winter Wheat has been found to be nearly one half of the dry weight of the entire plant; but a month later, when the growth of the stem and leaves has progressed, this proportion is reduced to about 20 per cent.

It is only in the perennial Grasses that the root can be employed as a reservoir; and without being specially modified for this purpose, its cells in these cases contain a large amount of reserve material.

Stem.—The special points to be considered in connection with the Grass stem are *laying* and *tillering*.

Tillering is merely the production of several stems from one seedling, and consists therefore in the branching of the primary axis.

A Grass seed, on germination, produces the primary stem bearing a few leaves, and it is while the nodes at which they are produced are separated from each other by very short internodes that branching takes place. In the Grass, as in other plants, branches always arise in the axils of leaves; but in this group of plants, it is in connection with the lowest leaves only that branches are produced, and consequently the lateral branches spring from the main stem quite close to the ground. Their number can never be very large, generally two or three, but from these secondary branches, others are produced which may again branch and rebranch, so that from one seed a tuft of

several stems may be produced. Tillering is often promoted when the main axis is destroyed; this property being of great advantage in pasture Grasses, for the grass when eaten down is able to produce new stems; it is also of importance in the cereals, for by this means several ears —in the case of Wheat sometimes as many as fifty or sixty—may be developed from one grain.

Laying.—After heavy storms a cornfield is not unfrequently seen with the crop in a great measure lying prostrate. This especially happens when the ears are well developed, and the plant has thus a tendency to be top-heavy. The "Laying" is due to the stem being of insufficient strength to resist the extra pressure of wind and rain. The reason of this want of strength must now demand our attention.

The analysis of a Grass shows a large quantity of *silica*, which gives great hardness and firmness to the cell-walls, and by some, it has been thought that the weakness of the stem was due to an insufficient supply of silica, and consequently to an imperfect development of the walls of the mechanical cells. The absence of silica, however, is not the cause of the weakness, for we have already seen (p. 120) that these plants grow equally well whether silica be present or not; and furthermore, the greater part of the silica in a Grass is found not in the stems, but in the leaves. Another theory advanced to account for laying is, that the presence of a too abundant supply of nitrogenous manures causes a multiplication of cells, and an imperfect development of their cell-walls. But neither is this the true explanation, for it is not found that plants growing on manure heaps are more prone to be "laid" than those in the fields. The real cause

of laying is the circumstance of the stem being insufficiently illuminated, especially in the lower internodes. It is a well-known fact that the stems and leaves of plants grown in the shade are longer and weaker than those fully exposed to the light, this greater length being caused by the increased size of the individual cells, the want of strength being due to the imperfect development of the cell-walls. In considering the structure of a Grass stem, it was explained that the necessary support is afforded by a cylinder of cells with thick hard walls just beneath the epidermis, by the strengthening cells surrounding the fibro-vascular bundles, and by the thickenings at the nodes. By a series of very careful experiments conducted on Rye, by shading the stems before they were fully grown, Dr L. Koch has shown that these stems suffer exactly in the manner just described. It was found that in the shaded plants the internodes were longer, and the strengthening cells less perfectly developed than those grown fully exposed to light. This will be at once recognised by a glance at fig. 52. *A* is a section from the internode of a plant grown in the open, the cell-walls are seen to be thick and hard ; *B* is from a shaded internode, and the cells are larger, their walls thinner and softer. The shaded internodes too are longer than those growing freely, and to support them would require a greater and not a less development of thick walled tissue.

A comparison of "laid" plants with those whose stems were artificially shaded showed an exact correspondence, the laid plants presenting the same want of development as the artificially shaded ones. Clearly, therefore, insufficient illumination is the true cause of laying.

This want of light may be brought about in various ways, chiefly by growing the plants too close together,

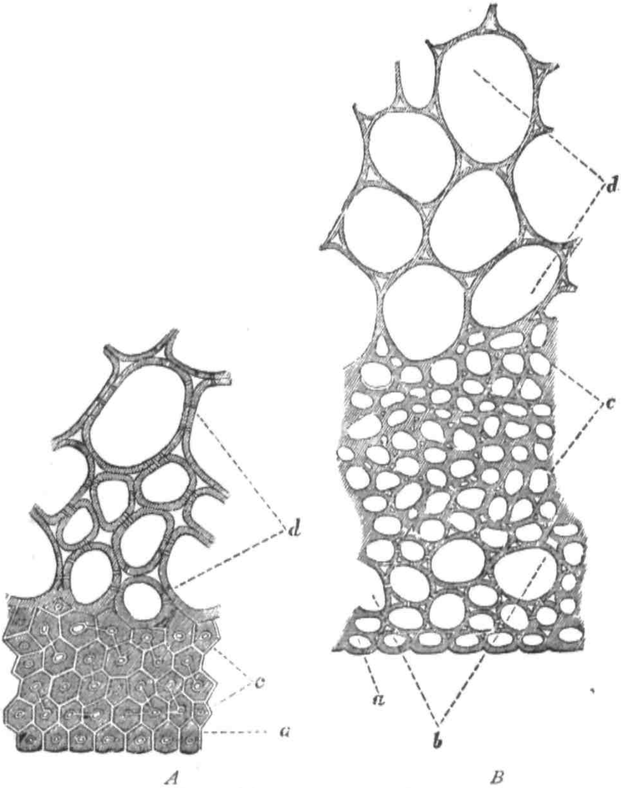


Fig. 52 (*from Vines, after Koch*).

A, transverse section of an internode of Rye (*Secale cereale*) grown fully exposed to light; B, similar section from a shaded internode, a, epidermis; c, strengthening cells.

in which positions the amount of light penetrating the

leaves would be insufficient for the proper development of the stem.

Leaf.—One of the most distinctive features of a Grass, and one by which a member of this family can at once be recognised, is the leaf, the two parts of which—the blade, and the sheath,—can be easily distinguished.

The *Sheath* (fig. 53), which is very characteristic of the Grasses, is merely a flattened petiole, which clasps round the stem for nearly the whole length of its internode, and thus affords it support. The edges of the sheath meet on the side opposite the blade, but never become joined together. The terminal sheath encloses and protects the inflorescence (fig. 46).

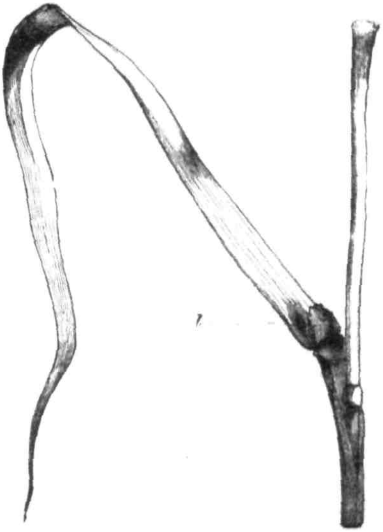


Fig. 53 (*from Figuier*).
Leaf of Millet (*Milium multiflorum*) showing blade, ligule (*l*), and split sheath.

The *Blade* is, in the majority of Grasses, very much longer than broad (fig. 53), and as a consequence, has its fibro-vascular bundles running parallel to each other, from one end of the leaf to the other, united, however, here and there by cross connections. The epidermal cells, too, have their longer axes parallel to the length

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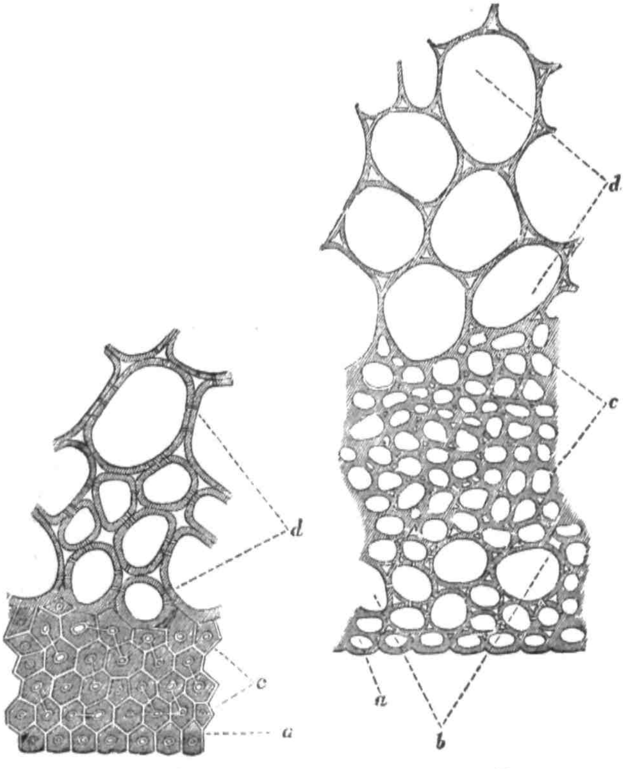

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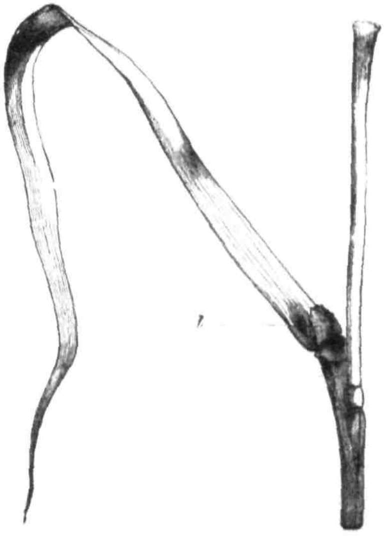

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of the blade, and the stoma (fig. 12) are also arranged in parallel rows, with the slits in the direction of the length of the blade.

The *Ligule*.—At the junction of the blade and sheath a small outgrowth (fig. 53, *l*) is found in the leaves of all Grasses, known as the *ligule*. The shape of the ligule varies very much in the different Grasses: it is on this account employed as a means to help in distinguishing one Grass from another. The ligule perhaps is a continuation of the sheath, and by clasping the stem assists the sheath in supporting the blade.

Inflorescence.—On the summit of the Grass stem is found the inflorescence, or collection of flowers, often termed the "ear." The individual flowers are wind-fertilised, and so are inconspicuous, and devoid of any showy parts. Each flower has protecting scales, which in some Grasses—*e.g.* Wheat,—form the chaff; and they are arranged in groups of one or a few flowers, which are termed *spikelets*.

A good example of an inflorescence is afforded by the Oat (fig. 54). In this Grass there is a central axis, bearing numerous branches, which in their turn branch again. The spikelets (fig. 58), each with two flowers, are borne on these branches. An inflorescence like that of the Oat is termed a *panicle;* other examples of panicles are afforded by the Quaking-grass (fig. 70), the Sheep's Fescue (fig. 64), the Yorkshire-fog (fig. 78). The Wheat is an example of an inflorescence in which the spikelets (fig. 58) have no stalks, and are thus borne directly upon the central axis, which is often toothed or notched to fit the spikelets, as in this instance. The spikelets are arranged in two or more rows upon the axis. Such an

inflorescence in the Grasses is termed an "ear" or spike: other examples are found in Rye-grass (fig. 86), and in the Barley.

The Spikelet of the Grass demands very careful attention, and on account of the minute size of many of them, their study is very difficult. But in the larger ones, such as the Oat or Wheat, the various parts can be made out with comparative ease.

If a spikelet of the Wheat (fig. 55) be removed, and its parts separated by a pair of needles, there will be found on the outside two boat-like scales enclosing another structure of similar nature. These outer scales are known as *glumes* (fig. 56, *g*), they are modified leaves. After removing the two glumes, the next structures are the *pales* (*b*, *b*),

Fig. 54 (*from Le Maout and Decaisne*).
Panicle of Oat (*Avena sativa.*)

very similar to the glumes, but provided with a stiff bristle — the *awn* (*gr*) — the pales are also modified leaves. Each pale will be found to enclose a smaller and more delicate pale (*ps*) without an awn. On removal of the pales, the *stamens* and *ovary* (fig. 57) will be exposed, but between the pales and the stamens two minute, delicate scales—*lodicules* (*sq*)—may be seen. The lodicules are in most Grasses very hard to find.

Fig. 55 (*after Le Maout and Decaisne*).
Spikelet of Wheat (*Triticum sativum*).

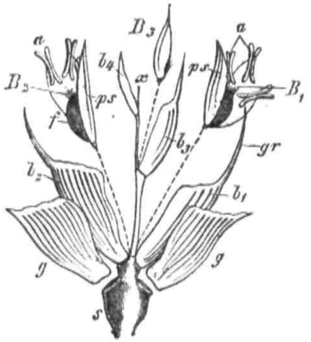


Fig. 56 (*from Prantl*).
Spikelet of Wheat dissected; *x*, axis of spikelet; *g*, glumes; b_1, b_2, outer pales; *gr*, awn; *B*, B_2, flowers displaced from the axils of the outer pales; *ps*, inner pales; *a*, anthers; *f*, ovary.

Though only differing slightly from the Wheat, the spikelet of the Oat (fig. 58) deserves a little attention: it contains two fertile flowers. The glumes (*G*) are large, and enclose the two flowers. One of the flowers with its outer pale (*Pe*) provided with the awn (*A*), and inner pale (*Pi*), is shown expanded in the figure, *F.S.* being the second flower. By removing the outer pale, the flower

with its ovary, stamens, and lodicules, may be exposed—in fig. 59 it is seen enclosed by the inner pale.

The spikelet of the Wheat will be found to contain two or three perfect flowers, with some barren ones (fig. 56, b_3, b_4), arranged on opposite sides of a central axis (x). A great deal of discussion has taken place with reference to the various parts of the flower, but we may consider the glumes as a pair of modified leaves which enclose and protect all the flowers of the spikelet. The number of

Fig. 57 (*from Le Maout and Decaisne*). Flower of Wheat (*Triticum sativum*). *sq.*, lodicules.

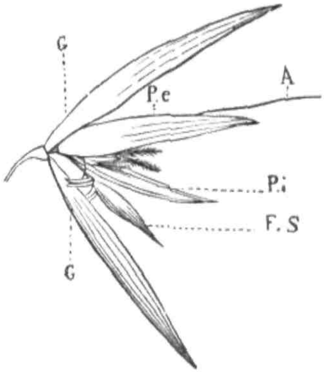


Fig. 58 (*from Le Maout and Decaisne*). Expanded spikelet of Oat (*Avena sativa*). *G*, glumes; *P.e.*, outer pale; *P.i.*, inner pale; *A*, awn; *F.S.*, second flower.

pales varies very much in the spikelets of the different Grasses, but there is always a pair of these structures to every perfect flower, which they enclose and protect. The outer pale is borne on the same axis as the glumes, and from its axil a minute shoot (in fig. 56 this is represented by a dotted line) is produced, on which the innepale and flower are borne. The outer pale then is the

leaf, in whose axil the flower is borne, and which in the usual botanical nomenclature would be termed a bract, and the inner pale a bracteole. The lodicules are regarded as the rudiments of a perianth, once possessed by the ancestral forms of these flowers, but which has now become much reduced and functionless as its flowers have become adapted for wind-fertilisation. The stamens are three in number (in the Rice and Bamboo six), with long filaments, and anthers containing a large amount of pollen. The ovary consists of two carpels, the presence of which is shown by the two feathery stigmas (fig. 57); it however contains only one ovule, and therefore each Grass flower requires only one pollen grain to fertilise it, and can produce only one seed. The ovule ripens into a seed which contains a large quantity of endosperm,—the position of the embryo being outside the endosperm, and on one side of the grain, near the base (page 103).

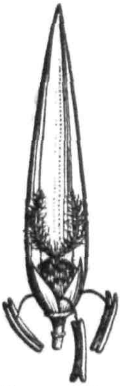


Fig. 59 (*from Le Maout and Decaisne*). Flower of Oat (*Avena sativa*) enclosed by inner pale.

In the Grasses the walls of the carpel (pericarp) never separate naturally from the seed, and hence a grain of Wheat, for example, surrounded by its pericarp, is botanically speaking a fruit, and not a seed.

When the fruit is shed it frequently happens that the pales are detached at the same time, and remain more or less firmly adhering to it. In many Grasses—Barley for instance—so close is this adhesion that some difficulty is experienced in effecting a separation. In the one-flowered spikelets, the whole spikelet may be shed with the fruit, so that what are often described as seeds are really fruits, enclosed by the pales and glumes (figs. 79 and 81).

The Grasses in the British flora number forty-six genera, but only twenty of these need be considered in this work, the remainder being rarely met with, or possessing few points of interest to the agriculturist.

The characteristics which separate one Grass from another are found in its various members, sometimes in the leaves, sometimes in the ligule or in the various parts of the spikelet, the difficulty in determining often being due to the minuteness of these structures and to the very slight degree of difference which exists between some of them.

Many Grasses present such striking features as to be recognised at a glance, and these are not easily confounded with others, but in some cases the distinctions are not so obvious, and it then becomes a matter of some difficulty to exactly determine the species.

Determination of Grasses.*—For this purpose it is convenient to divide the Grasses into two sections :—

SECTION I. IN WHICH THE SPIKELETS ARE STALKED, AND GENERALLY ARRANGED IN AN OPEN PANICLE, THOUGH SOMETIMES IN A CYLINDRICAL SPIKE.

This section may be divided into three groups :—*A*, in which the spikelets have two or more perfect flowers; *B*, in which there is one perfect flower and a rudimentary one; and *C*, in which the entire spikelet consists of one flower with its two glumes and two pales.

A. Spikelets with two or more perfect flowers.

The awns must now be examined. The first five genera

* Adapted from W. R. Hayward's "Botanist's Pocket-Book" (Messrs Bell & Sons).

have awns, while in the remaining four this structure is absent.

I. Flowers awned.

The first three genera are distinguished by having the lower pale forked at the summit, while in the remaining two the lower pale terminates in a single point.

a. Lower pale forked.

AIRA, *distinguished by its bent awn, and the glumes equalling the lower flower.* 6 species.

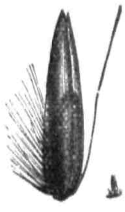


Fig. 60. "Seed" of Hassocks (*Aira cæspitosa*).

A. cæspitosa (fig. 60) is a common grass, forming large tufts of dark green, coarse leaves, raised somewhat above the level of the ground, from which arise long slender stems, bearing beautifully branched panicles. The tufts are popularly known as "Hassocks," "Bull's faces," "Rough cap." The "seeds" of *A. cæspitosa* are used to adulterate other grass "seeds."

AVENA, *awn twisted; glumes as long as the lower flower.* 5 species.

Avena. This genus comprises the various kinds of Oats, and 5 species of British grasses.

A. sativa is the common Oat (fig. 54), of which there are four varieties, distinguished by the number of spikelets, the colour of the glumes and pales, and the length of the corn.

A. orientalis—the Tartarian Oat—is recognised by the spikelets being all arranged on one side.

A. nuda is known by the fruit not adhering to the pales.

A. flavescens—the Yellow Oat-grass (fig. 61) common in fields, is recognised by its obtuse ligule, and hairy stem and leaves. At the time of flowering its panicle is widely spread on all sides. It is a valuable grass, from 1-2 feet high; flowers in June or July, and ripens its grain in August.

A. fatua — Wild Oat — is a troublesome weed in corn-fields. Spikelets with three flowers; 2-3 feet high.

A. pratensis—Narrowed-leaved Oat—has three to six flowers in the spikelets; found in dry pastures; 12-18 inches high.

BROMUS — Brome - grass — *Awn straight; glumes shorter than the lower floret.* 10 species. Generally considered to be weeds. The "seeds" of *B. mollis*, and *B. secalinus*, are often found among other grass "seeds."

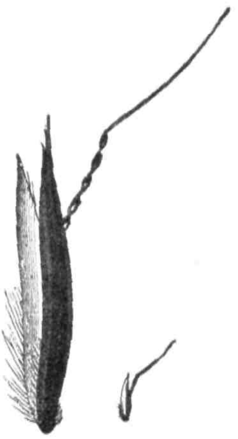


Fig. 61.
"Seed" of Yellow Oat-grass (*Avena flavescens*).

b. Lower pale entire.

DACTYLIS. *Spikelets crowded; nearly all turned towards one side; fruit free from pale.* 1 species.

Dactylis glomerata—Cock's-foot (figs. 62 and 63), so named from the fancied resemblance of the inflorescence to a cock's foot. It is a large and coarse-looking grass, found growing in nearly all situations, and is said to be among the most valuable of all the Grasses. Leaves broad; ligule well developed; 1-2 ft.

FESTUCA—Fescue—*Spikelets mostly in a one-sided panicle; fruit adhering to the pale.* 7 species.

The Fescues may be divided into the narrow and the broad leaved.

narrow leaves.

F. ovina—Sheep's Fescue—(figs. 64 and 65) forms tufts of very fine leaves. Four varieties are known of this grass.

(*a*) *F. duriuscula* — Hard Fescue—(fig. 66). Stem erect, 1-2 feet high, not so much tufted as *F. ovina*. Valuable in sheep pastures.

(*b*) *F. tenuifolia*. Leaves very slender. Valuable in sheep pastures.

(*c*) *F. rubra*. Stem creeping; lower leaf sheaths of a dull red.

(*d*) *F. heterophylla*. Leaves various, the upper ones flat and the lower folded.

Fig. 62 (*from Fitch and Smith*). Cock's-foot (*Dactylis glomerata*).

Fig. 63. "Seed" of Cock's-foot (*Dactylis glomerata*).

broad leaves.

F. pratensis—Meadow Fescue (fig. 67). A tall grass (1-2 ft.) with panicle drooping to one side. A very valuable grass.

F. loliacea—Spike Fescue—is a variety of *F. pratensis*, with spikelets having no stalks, and destitute of an awn.

F. elatior—Tall Fescue—grows much higher than *F. pratensis*, which it very much resembles, but is coarser looking, and has spreading panicles.

Fig. 67.
"Seed" of Meadow Fescue (*Festuca pratensis*).

Fig. 66.
"Seed" of Hard Fescue (*Festuca duriuscula*).

Fig. 64 (*from Burgtorf*).
Sheep's Fescue (*Festuca ovina*)

Fig. 65.
"Seed" of Sheep's Fescue (*Festuca ovina*).

II. Florets without awns.

CYNOSURUS. ***Spikelets with very short stalk, springing from the axil of a scale leaf nearly as large as the spikelet, having deeply cut edges.*** 2 species.

C. cristatus—Crested Dog's-tail—(figs. 68 and 69), a very common grass in pasture, and easily recognised by its inflorescence. It is much more valuable as a pasture grass than for hay. The leaves are slender—the stems are hard and wiry after flowering, and are left untouched by stock; they remain for a long time before decaying. 1-2 feet.

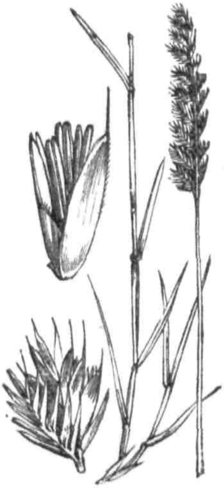


Fig. 69.
"Seed" of Crested Dog's-tail (*Cynosurus cristatus*).

Fig. 68 (*from Fitch and Smith*).
Crested Dog's-tail (*Cynosurus cristatus*).

Fig. 70 (*from Fitch and Smith*).
Quaking-grass (*Briza media*.)

BRIZA. *Glumes boat shaped, obtuse; fruit adhering to pales.* 2 species.

B. media—Quaking-grass—(fig. 70), a common grass in many meadows and roadsides—generally considered to be worthless.

POA—Meadow-grass. *Glumes unequal, acute; the*

outer pale compressed, with 3-5 parallel veins; panicle spreading. 7 species.

P. annua is best known as a very common weed found universally in flower beds, gravel walks, and waste places. 2-10 inches.

P. pratensis (figs. 71 and 72)—Smooth Meadow-grass,

Fig. 71 (*from Fitch and Smith*). Smooth Meadow-grass (*Poa pratensis*).

Fig. 73. "Seed" of Wood Meadow-grass (*Poa nemoralis*).

Fig. 72. "Seed" of Smooth Meadow-grass (*Poa pratensis*.)

Fig. 74. "Seed" of Rough stalked Meadow-grass (*Poa trivialis*).

recognised by its roots keeping near to the surface. By some authorities it is considered to be a weed. 1-2 feet.

P. nemoralis (fig. 73)—Wood Meadow-grass, found growing in shady places. Valuable on account of its early growth. 1-3 feet.

P. trivialis (fig. 74)—Rough-stalked Meadow-grass, recognised by its rough stem and leaves. 1-2 feet.

The "seeds" of the Poas have all a fine tuft of hairs at their base, which prevents their being easily distinguished one from the other.

GLYCERIA—Water Meadow-grass—is distinguished from Poa chiefly by its *obtuse glumes*. 2 species.

G. fluitans and *G. aquatica* are found growing near the

Fig. 75 (*from Fitch and Smith*). Sweet-scented Vernal-grass (*Anthoxanthum odoratum*).

Fig. 76. "Seed" of Sweet-scented Vernal-grass (*Anthoxanthum odoratum*).

water's edge in ponds, ditches, and streams. They are valuable grasses in wet lands and fenny districts.

B. Spikelets with one perfect flower, and one or more rudimentary or barren ones.

This class is divided into two sections, the first of which has only one genus and is characterised by the spikelets being crowded together to resemble a spike; the second has open panicles.

a. Spikelets in an interrupted, spike-like panicle.

ANTHOXANTHUM. *Stamens 2; glumes unequal.* 1 species.

A. odoratum—Sweet-scented Vernal-grass (figs. 75 and 76). A common grass in meadows and pastures, remarkable for the early appearance of its flowers, which continue to bloom until late in the autumn. It is also noted for its sweet scent, and gives the characteristic odour to new-mown hay. It tillers freely and grows in tufts. 1-2 feet.

A. puelii (fig. 77) is an annual species, found plentifully in Germany; it is quite worthless, but its "seeds" are often sold as those of *A. odoratum.*

Fig. 77.
"Seed" of Puel's Vernal-grass (*Anthoxanthum Puelii*).

b. Spikelets in an open panicle.

HOLCUS. *Upper flower with stamens only, awned; lower perfect, unawned.* 2 species.

H. lanatus—Yorkshire-fog—(figs. 78 and 79) is a common grass from 12-18 inches high, sometimes known as "Soft grass," from the softness of its stems and leaves, and from the hairs which are distributed over the whole surface. It has a bitter taste, which is disliked by stock. Yorkshire-fog, though very common, is of little value, and must be

regarded as a weed, since it occupies space which would be more profitably filled by other grasses.

H. mollis very closely resembles *H. lanatus*, but it is only hairy at the nodes, and has a creeping habit; the awn also is rough throughout, and is not concealed. It occurs in meadows and road-sides, and like *H. lanatus* is a weed.

ARRHENATHERUM. *Upper flower perfect, with short, straight awn; lower barren with long awn.* 1 species.

A. avenaceum—False Oat-grass—is a tall grass (2-3 feet) common in

Fig. 78 (*from Burgtorf*).
Yorkshire-fog (*Holcus lanatus*).

Fig. 79.
"Seed" of Yorkshire-fog (*Holcus lanatus*)

hedge-rows and in arable land. The lower internodes are often so much swollen as to resemble small

onions joined together, hence it is often called "Onion-twitch." In arable lands it is a weed, but is thought to possess qualities of value to the agriculturist.

Fig. 80 (*from Burgtorf*).
Meadow Fox-tail (*Alopecurus pratensis*).

C. Spikelets with one perfect flower, and no rudimentary or barren ones.

Divided into two sections; the first, with two genera, has dense, cylindrical spikes; the second has spikelets in a lax panicle.

Fig. 81.
"Seed" of Meadow Fox-tail (*Alopecurus pratensis*).

a. Spikelets in a dense cylindrical spike.

ALOPECURUS. *Pale awned.* 6 species.

A. pratensis—Meadow Fox-tail (figs. 80 and 81)—an early grass well able to endure cold. It is one of the most valuable of all the Grasses, producing a large quantity of herbage in the early spring. The spikelets are of a silvery grey colour and borne on short stalks, the inflorescence being a spike about twice as long as it is broad and bluntly pointed. 1-2 feet.

Fig. 82.
"Seed" of Black-grass (*Alopecurus agrestis*).

A. agrestis—Black-grass—(fig. 82), a most troublesome weed, distinguished from *A. pratensis* by its longer and more slender spike, by its rough stem and longer awn. 1-2 feet.

A. geniculatus—Floating Meadow-grass—is a common creeping grass found by the water-side or in damp situations. Its stem is bent at the nodes. It is of little or no agricultural value. 6-12 inches.

PHLEUM. *Pale unawned.* 4 species.

P. pratense—Cat's-tail—(figs. 83 and 84), a large grass about 2-3 feet high. It somewhat resembles Fox-tail, but is easily distinguished from the latter by its coarser appearance, and its very much longer spike, without awn. The Fox-tail flowers much earlier than the Cat's-tail, the latter flowering about July. This grass is also known as "Timothy" and was so-called after T. Hanson, who

introduced its cultivation about the middle of last century.

b. Spikelets in a lax panicle.

AGROSTIS. *Glumes unequal, the upper being the smaller; outer pale unawned.*

A. vulgaris—Bent-grass—(fig. 85), a small plant about 12-18 inches high, with spreading panicle and short, truncate ligule. Very common in pastures and in arable land, in which latter situation it is sometimes mistaken for Couch-grass. It possesses little or no value.

A. alba — Marsh Bent—is a much larger grass (from 1-2 feet).

Fig. 84.
"Seed" of Cat's-tail
(*Phleum pratense*).

Fig. 83 (*from Burgtorf*).
Cat's-tail (*Phleum pratense*).

The panicle becomes compact after flowering; ligule long

and pointed. The variety *A. alba stolonifera*—Fiorin—recognised by its long, prostrate stems, is a late grass and affords pasture late in the year. 1-2 feet.

SECTION II. THE SPIKELETS ARE WITHOUT STALKS AND ATTACHED TO A TOOTHED OR JOINTED MAIN AXIS FORMING A TRUE SPIKE.

In this section we need only consider four genera.

TRITICUM. *Spikelets solitary, broadside to the main axis; many-flowered; glumes equal.*

Fig. 85 (*from Burgtorf*). Bent-grass (*Agrostis vulgaris*).

Triticum. This genus comprises the various kinds of Wheat and a few other Grasses. Seven species of *Triticum* are cultivated as Wheat:—*T. vulgaris* (common Wheat); *T. durum*; *T. polonicum*; *T. turgidum* (English Wheat); *T. spelta* (Spelt); *T. dicoccum*; *T. monococcum*. A very large number of varieties of these species are known, and cultivated.

Triticum repens — "Twitch," "Scutch," "Couch," "Whickens"—is a common, and troublesome weed in arable land. Its ears, which resemble those of the Wheat but are larger and more slender, may often be seen

in hedge-rows. Awns small. The method of reproduction, which enables this plant to spread so rapidly, has already been considered.

T. junceum is a common grass on sand dunes, and helps by its underground stem and roots to bind the sand and to hinder its being blown about by the wind.

LOLIUM. *Spikelets solitary, edgewise to main axis;*

Fig. 86 (*from Fitch and Smith*). Rye-grass (*Lolium perenne*).

Fig. 87. "Seed" of Rye-grass (*Lolium perenne*).

many-flowered; glumes, one, or the inner one if present is much smaller.

Lolium perenne—Common Rye-grass—(figs. 86 and 87), a common grass very often found on road-sides, and railway embankments. It is very easily distinguished by the spikelets arranged in two rows on opposite sides of the main axis, and placed edgewise to it. Common Rye-grass

is perennial and tillers very freely, and on this account is most useful as a pasture grass; it is also valuable for hay.

L. italicum—Italian Rye-grass—(fig. 88) is much larger and more vigorous than common Rye-grass, from which it is easily distinguished by its larger size and by its long awns. Its useful properties are the same as those of the common Rye-grass, and by some authorities it is considered to be only a cultivated form of this.

Fig. 88.
Seed" of Italian Rye-grass (*Lolium italicum*).

HORDEUM. *Spikelets arranged in threes, with one flower each; pales with long awn.*

Hordeum—Barley—of which four species are found growing wild in this country. In the Barley the fruit adheres to the pale.

H. distichum is the common Barley. The ear has a row of perfect spikelets placed opposite to each other on the main axis, while on each side of these there is a barren, and imperfectly developed spikelet.

H. vulgare has a four-rowed ear. In addition to the two fertile spikelets, two of the usually barren ones are fertile, this cause bringing about the four rows.

H. hexastichum, the six-sided Barley, has all the spikelets fertile.

NARDUS. *Spikelets solitary, and arranged in two rows on the same side of the main axis.* 1 species.

Nardus stricta—Mat-grass—a common grass on moors. From 8-10 inches high, with bristle-like leaves.

CHAPTER XII.

LEGUMINOSÆ.

The Leguminosæ are a very large family of plants inhabiting nearly all countries of the globe. The chief characteristic which connects the various members of this order is the fruit, which is always composed of a single carpel and ripens into the well-known pod or *legume*, the name given to a fruit of one carpel which opens along both edges. Some of the fruits contain only one seed, these therefore have no necessity to open. The flowers may be irregular, as in the Pea; or may be quite regular, generally with five sepals, five petals, and ten stamens; the sepals, petals, and stamens arising from the edge of the cup-shaped axis.

The leaves are never arranged opposite to each other; they are generally compound, with a varying number of leaflets placed on opposite sides of the leaf-stalk, at the base of which a pair of stipules are to be found. The seed is exendospermous, and in many of these plants it is of great value as a food material, for which reason they have been cultivated from a very remote period.

The order comprises Trees, Shrubs, and Herbs; it is divided into three sub-orders:—

I. Mimoseæ.—Chiefly tropical trees, characterised by their

regular flowers, clustered into globular heads. Examples *Mimosa*, *Acacia*.

II. Cæsalpinæe.—Trees or shrubs, chiefly tropical. Their flowers resemble those of the Papilionaceæ, but differ in having the standard situated inside the wings.

III. Papilionaceæ.—This sub-order consists for the most part of herbs and shrubs, which flourish in temperate regions. They are distinguished by their compound leaves with stipules. The leaflets are modified in several instances to serve as tendrils (fig. 93). The members of this sub-order are easily recognised by the structure and arrangement of the various parts of the flower, which is very distinctive,—a typical example being afforded by the Pea, which we have already fully described.

The Papilionaceæ is a large order, of which eighteen genera are natives of this country, a great proportion of these being useful in Agriculture either when grown as crops or as pasture plants. The only members of the Leguminosæ which are grown as crops in this country belong to the Papilionaceæ, and on this account the term "Leguminous plants" has come to be commonly applied only to this sub-order, which includes such plants as *Peas*, *Beans*, *Vetches*, *Lupins*, *Clovers*, *San-foin*, &c.

The genera may be conveniently divided into two groups, those whose stamens are all united, and those in which the upper stamens are not joined with the rest.

A. *Stamens all united.*

ULEX—the Gorse, Furze, or Whin, has simple spiny leaves and yellow flowers. The young plants have tender stems and leaves, and are therefore sometimes grown for fodder.

SAROTHAMNUS—the Broom, is common on sandy waste lands.

ONONIS—a small plant with pink flower, commonly known as the "Rest Harrow." There are two species, one with spines and one without.

ANTHYLLIS—the Kidney Vetch or "Ladies' fingers," is common on chalky lands, and may be recognised by its yellow flowers, and white hairs on calyx.

B. *Upper stamens not united with the rest.*

MEDICAGO—Medick, recognised by the spirally twisted pod. 6 species.

M. lupulina (fig. 89)—Black Medick or "Nonsuch," is a small plant (6-24 inches), with procumbent stem, yellow flowers clustered together, and black, one-seeded fruits. It very closely resembles some of the smaller species of *Trifolium*, but is easily distinguished from them by its fruits.

Fig. 89 (*from Fitch and Smith*). Black Medick (*Medicago lupulina*).

M. sativa—Lucerne, Purple Medick, is a much larger plant, with an erect stem from 1-2 feet high. It has purple flowers, and pod twisted spirally two or three times.

MELILOTUS—Melilot or Bokhara Clover. Flowers arranged on one side of the flower-stalk, with nearly straight pods. 3 species.

M. officinalis—the common Melilot, a tall plant from 2-3 feet high, with yellow flowers.

TRIFOLIUM—Clover. Flowers clustered into heads, with the calyx teeth of unequal length. 20 species.

T. repens (fig. 90)—White or Dutch Clover. A small plant with both creeping and erect stems, the former root at the nodes, while the latter bear leaves and flowers, and vary from 3-18 inches in height. The leaves are often marked across the centre with a lighter V-shaped band. Flowers usually white. A very useful plant.

Fig. 90 (*from Fitch and Smith*). White Clover (*Trifolium repens*).

Fig. 91 (*from Fitch and Smith*). Purple Clover (*Trifolium pratense*).

T. incarnatum—Crimson Clover, is an annual plant from 6-18 inches high. It may be distinguished by its crimson flowers arranged in an elongated head.

T. pratense (fig. 91)—Common Purple Clover, very frequently cultivated. It grows from 6-18 inches in height. Stem partially erect. Leaves with broad white V-shaped band. Flowers densely clustered together.

T. pratense perenne is often designated "Cow-grass," but this is a bad term, as it is not a Grass. It is merely a variety of *T. pratense*, from which it may be distinguished by its much smoother stem and larger stipules.

T. hybridum (fig. 92)—Alsike Clover, is not a native of this country but has been introduced for purposes of cultivation. It has an erect stem. Flowers white or pale pink. Corolla persistent, turning brown. Pods with 2-4 seeds.

Fig. 92 (*from Fitch and Smith*). Alsike Clover (*Trifolium hybridum*).

T. procumbens—Hop Trefoil, is a small plant found in pastures. Stem creeping. Flowers very numerous, bright yellow, and clustered into heads. It is liable to be confounded with *Medicago lupulina*, but may be distinguished from this by the persistent, brown, faded corolla which covers the fruit.

T. minus—Lesser Yellow Trefoil, is a smaller plant than the preceding one, and has fewer flowers in the heads, about 10-15.

T. avense—Hare's-foot Trefoil, is recognised by the calyx being longer than the corolla and produced into feathery teeth. It is found in sandy districts, and grows from 6-12 inches in height.

LOTUS—Bird's-foot Trefoil, has its calyx teeth equal in length. Pod with many seeds. 3 species.

L. corniculatus—Common Bird's-foot Trefoil, "Eggs and

Bacon," "Lamb's Toes," is common in dry situations, and grows from 4-18 inches high. The stem, from which the erect flower stalks arise, is creeping. At first the flowers are of a reddish colour, which changes afterwards to a bright yellow as they open.

ONOBRYCHIS—Sain-foin. 1 species.

O. sativa is found on chalky pastures, growing from 1-2 feet high. Stem erect. Leaves with many leaflets. Flowers in an elongated head. The fruit becomes wrinkled when ripe, and contains only one seed.

Fig. 93 (*from Fitch and Smith*). Common Vetch (*Vicia sativa*).

VICIA—the Vetch or Tare. Leaves with numerous lateral leaflets, the upper ones generally modified into tendrils (fig. 93). Style cylindrical. 10 species.

V. cracca—Tufted Vetch, is a common climbing plant with narrow hairy leaves.

V. sativa—Common Vetch (fig. 93), has weak stem, partly erect. Flowers purple, and often arranged in pairs. Often cultivated.

V. hirsuta—A very hairy plant, frequent in waste places and a weed in cornfields. About six flowers are grouped together.

V. faba—the Field Bean, is not indigenous, but has been introduced from the East. The Broad Bean and Windsor Bean are merely varieties of the Field Bean.

LATHYRUS—Everlasting Pea, closely resembles *Vicia*,

but is distinguished by the flattened style. 10 species.

LUPINUS—Lupin, is easily recognised by the leaves, which are digitate—that is, the leaflets spring from the extremity of the leaf stalk. Although not a native of this country several species are grown. The Blue Lupin is a common plant in gardens. *L. luteus*, Yellow Lupin, is cultivated in Germany.

Pisum sativum (Pea), *Phaseolus multiflorus* (Scarlet Runner), *Ervum lens* (Lentil) have all been introduced into this country. In common with many Agricultural plants, their origin is obscure, since they have been under cultivation from pre-historic times. They have most probably been introduced from the East with the exception of *Phaseolus*, which appears to be a native of Central America.

NITROGEN IN THE LEGUMINOSÆ.

The peculiar relationship between the Leguminosæ and nitrogen has been mentioned in the chapter on Food, but the subject demands a special consideration on account of the great agricultural importance of this family of plants.

The Leguminosæ, it is well known, are very rich in nitrogen, and are therefore often described as "Nitrogen Collectors." But the source from which this large amount of nitrogen is obtained, and the means employed by these plants to secure it, has long been a puzzle, and even at the present time it cannot be said that a complete solution to the problem has been found.

A good idea of the large amount of nitrogen in the Leguminosæ may be obtained from the experiments at Rothamstead of Sir J. B. Lawes and Dr Gilbert, who found

that Beans yielded twice as much nitrogen as either Wheat or Barley, and more than twice as much as did a Root-crop, when grown under similar conditions; also, that a Leguminous crop accumulates a great deal more nitrogen over a given area than a Gramineous crop under equal conditions of soil. This nitrogen would be contained in the aerial parts of the plant, but a large amount is also left behind in the soil. The Leguminosæ, therefore, although collecting such large quantities of nitrogen, do not exhaust this element from the soil, but, on the contrary, the soil in which they have been grown is found to be richer in nitrogen than before.

It is most remarkable that the Leguminosæ, which contain so large a proportion of nitrogen, are able to obtain their own supplies of this element, and to flourish, without its being actually given to them in the ordinary way. Thus the Rothamstead experiments show that they flourish when supplied with manures containing all the food elements except nitrogen, and that when this is added there is comparatively little additional increase. This is well exemplified in fig. 94, taken from the result of experiments on Vetches by Professor Wagner of Darmstadt. The first two pots (O) have received no manure, and hence the plants grown in them are dwarfed; the centre pots (KP) have received potash and phosphorus, and as a consequence the plants in them are well grown and vigorous; the growth of the plants in the pots (KPS) is little better than in the others, although nitrogen has been given to them.

The Leguminosæ, then, not only are much richer in nitrogen than other plants, but do not draw upon the ordinary supplies for this element. We must therefore

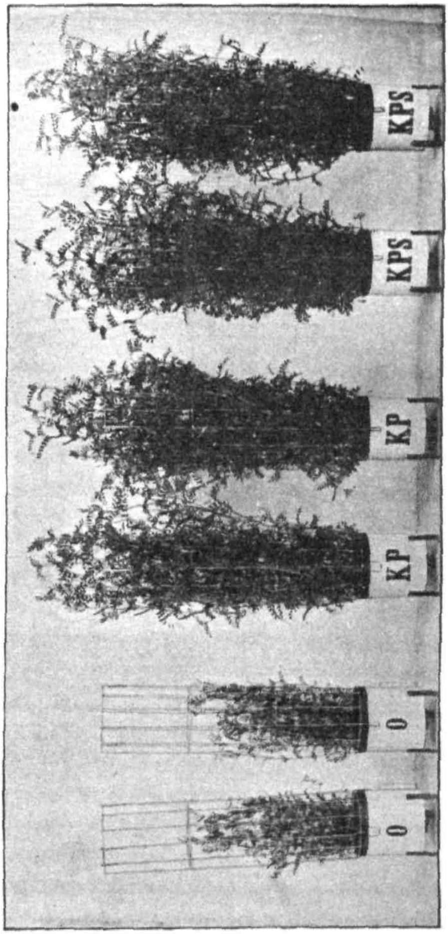


Fig. 94 (*from Wagner*).
Experiments with Vetches in relation to nitrogen.

look for some other source from which they obtain it in such large quantities.

Sources of Nitrogen for the Leguminosæ.—That the

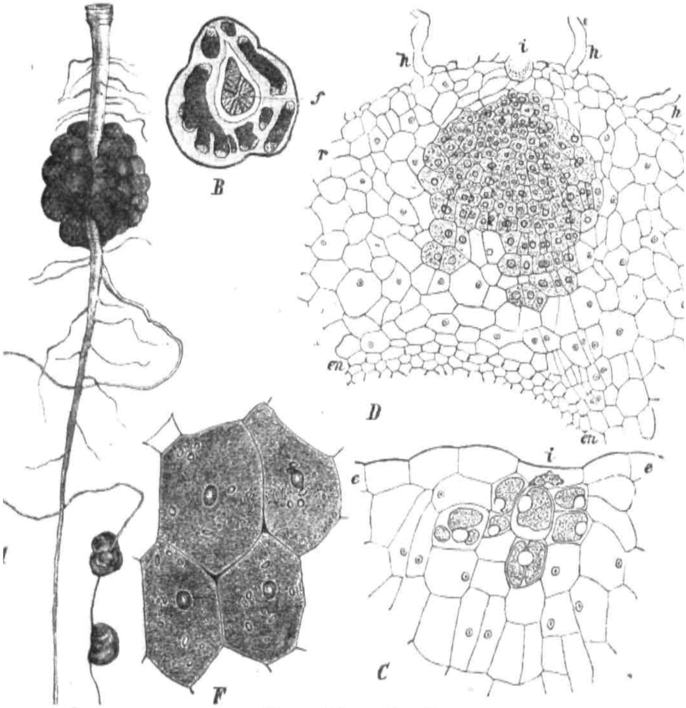


Fig. 95 (*from Frank*).

A, Lupin root with tubercles. *B*, transverse section of a tubercle; *f*, fibro-vascular bundle; the dark masses round it are the infected cells. *C*, first stage in the infection, *e*, *e*, cells of piliferous layer; *i*, point of infection (× 175). *D*, further stage in development of the nodule; *h*, root hairs; *i*, point of infection; *r*, cortex; *en*, bundle sheath (× 70). *F*, four cells in the "mycoplasma" stage (× 230).

supplies are not necessarily derived from the soil is shown by the experiments just mentioned. The air, then, is the

only other available source, and doubts have arisen as to the truth of the conclusion that plants are incapable of utilising this abundant supply. The experimental evidence however, proves that in this respect the Leguminosæ do not possess any peculiar properties, and that the nitrogen of the air is not directly available for these, or for other similar plants. But that the nitrogen of the air is somehow or other brought into service for them, there can be little doubt. Micro-organisms of a somewhat similar nature to those which play so important a part in the process of nitrification, are very common in the soil, and some of these seem to have the power of fixing the atmospheric nitrogen, *i.e.*, bringing it into combination as a preliminary step to its undergoing nitrification, and becoming thereby a source of food for the higher plants. Certain micro-organisms in this way are intimately associated with the Leguminosæ, and provide them with nitrogen from the air.

For a long time it has been well known that the roots of the various Leguminous plants have numerous swellings upon them. These swellings (fig. 95, A) are the well-known *nodules* or *tubercles*, and vary very much in size, sometimes being little larger than a pin's head, at other times as large as a pea, or even much larger. These tubercles have always been a matter of interest, but at no time have they excited so much controversy as at the present, though it has been generally acknowledged that it is through them that the problem of the supplies of nitrogen to the Leguminosæ, receives a solution.

A transverse section through a root and tubercle (B) shows that the central fibro-vascular cylinder is only slightly altered, but that in the ground tissue there are masses of

opaque cells, and that the tubercle is due to an increase in the cells of the ground tissue. Increased magnification reveals the fact that the cells shown as dark masses in B, are parenchymatous cells filled with protoplasmic contents; these are usually known as the *infected-cells*. At their edges there are groups of smaller dividing cells (fig. 96, E, *m*), by which the number of the infected cells is

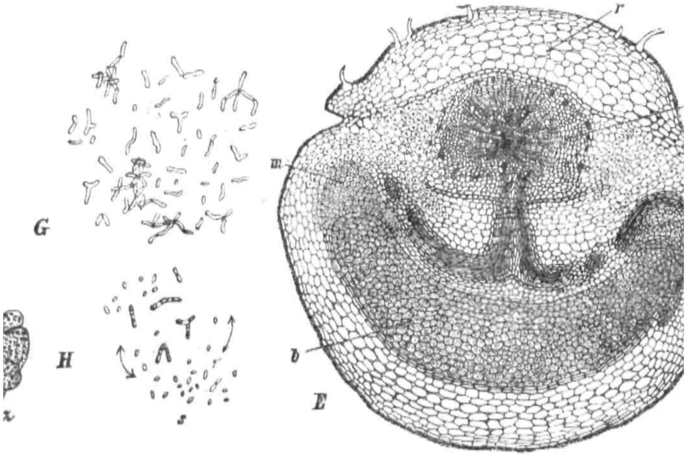


Fig. 96 (*from Frank*).

E, section of tubercle still further advanced; *b*, infected cells; *f*, fibro-vascular bundle, from which a branch extends towards the infected cells; *m*, dividing cells; *r*, cortex. *G*, Bacteria from the cells in *F* (× 1090). *H*, Bacteria cultivated on gelatine; *s*, swarming; *z*, in a jelly-like mass (× 1090).

increased. A branch from the fibro-vascular cylinder is extended to these infected-cells which are surrounded by ordinary ground tissue cells (*r*).

The infected-cells (fig. 95, F) are densely filled with protoplasm, which, according to Frank, is not the original protoplasm of the cell, but is the cell protoplasm combined with certain micro-organisms (bacteria), to form what is termed

a *mycoplasma.* Other authorities dispute that the cell protoplasm combines with the bacteria, but all are agreed that numerous bacteria are present in these cells. The bacteria, when fully grown, are often seen as V or Y shaped bodies (fig. 96, G). When removed from the tubercle they have been cultivated in a drop of nutrient fluid, under which conditions they give rise to a number of very much smaller bodies (H, *s*), which swarm about for a time, or may unite into a jelly-like mass (H, *z*). Other plants have been infected from these cultures.

We may now trace the entrance of the bacteria into the plant. The particular bacteria which associate with the Leguminosæ, in some form are present in the soil, and should they come in contact with a suitable root, are able to infect it. In the Lupin (C) the bacteria enter through the cells of the piliferous layer (as at D, *i*) and soon commence to penetrate from cell to cell, causing an increase in the number and size of the ground tissue cells until a tubercle is formed (D). In other plants, as the Broad Bean (*Vicia faba*), the first commencement of the tubercle is the infection of a root at some part of a root-hair. From this point a hypha without septa passes down the root-hair, and entering into the cells of the ground tissue, there branches and rebranches. Certain of the finer branches end blindly in these cells and commence to bud off a number of bacteria, the consequent multiplication of cells resulting in the formation of the tubercle.

The tubercles are very common in nature, and it may be doubted whether a Leguminous plant when growing under natural conditions is ever free from them. Any treatment which will kill the bacteria in the soil will of course prevent

the formation of these tubercles: thus, if soil be heated to the boiling point these organisms are killed, or if a seed of a Leguminous plant be planted in sterilised soil, no tubercles can be formed until the bacteria are introduced, either by the addition of some unsterilised soil, or by watering the plant with a watery extract of soil containing these bacteria.

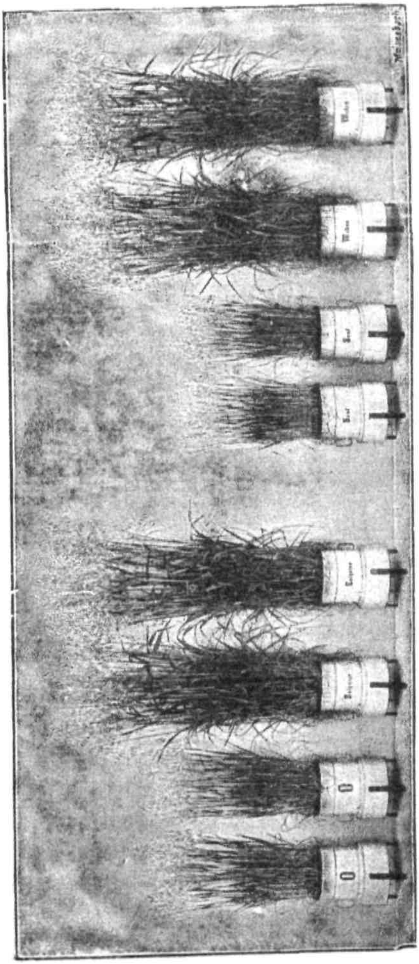
Numerous experiments, notably by Hellriegel and Willfarth, Frank and others, have shown that it is only when the tubercles are formed that the Leguminosæ are able to flourish without supplementary supplies of nitrogen being given to them.

The Leguminous plants grown in sterilised soil, with all the food elements except nitrogen, starve for the want of this element, since no tubercles can be developed; but when the sterilised soil is infected with the bacteria, then the tubercles are formed and the plants, no longer suffering from the absence of nitrogen, develop and become vigorous.

As a confirmation of this theory, Frank has shown that the mycelia of certain fungi are associated with the smaller roots of many large trees, as Oaks, Pines, &c., and help to supply them with nitrogen in a similar way, and he has also proved that the development of young Pine trees is greatly enhanced by the presence of these fungi.

Green Manuring.—The nitrogen accumulated by the Leguminosæ can be turned to account as a means of providing this element for other plants, such as the cereals which must have an available supply, but have not the peculiar faculty of procuring it possessed by the Leguminosæ. Thus, Sir J. B. Lawes and Dr Gilbert found that Barley, when grown immediately after a crop of Clover, yielded upwards of twice as much

GREEN MANURING WITH OATS.



Potash, Phosphorus, no Nitrogen.

Potash, Phosphorus, 150 grains of Nitrate of Soda per pot.

Fig. 97 (*from Wagner*).

Potash, Phosphorus, no Nitrogen. White Mustard buried green.

Potash, Phosphorus, no Nitrogen. Vetches buried green.

nitrogen as when grown after Barley, although a large quantity of nitrogen had been removed in the Clover crop.

A further extension of this principle is the process of "Green Manuring," in which various Leguminous plants, such as Lupins, Vetches, Clover, Peas, are sown into the crop and then ploughed into the land when green, to decompose and furnish supplies of nitrogen for the succeeding crop. Figure 97 presents an example of this method with Oats and Vetches. The two pots (O) contain Oats, which, although manured with potash and phosphorus, yet had no nitrogen presented to them, and hence are dwarfed; the two pots next to them were similarly treated, but had in addition nitrate of soda; the next two pots, like the first two, had no nitrogen, but White Mustard had been grown in the previous year and buried green. This plant, one of the Cruciferæ, is not rich in nitrogen, and hence we see that the Oats are starved as in the first pots. The appearance of the plants in the last pot, however, is very different, the growth being quite as luxuriant as in those to which nitrate of soda was supplied, the requisite amount of nitrogen having been obtained from the decomposition of the Vetches grown in the previous year and buried while green.

The comparative failure of the Oats grown after White Mustard, shows that it is not every plant which may be utilised for the purpose of Green Manuring.

CHAPTER XIII.

THE CLASSIFICATION OF PLANTS.

A STUDY of Agricultural Botany can hardly be considered complete without some knowledge of the great natural divisions into which the various groups of plants may be arranged, and their affinities one with another. This last chapter is therefore devoted to a brief summary of the Classification of plants, with an account of the chief characteristics of the different groups, dealing only with those which are of the most importance to our main theme. The Gramineæ and Leguminosæ being of such special importance in Agriculture, require a fuller treatment than is consistent with this short review; they have therefore been considered separately, and here merely take their proper relative positions.

The vegetable kingdom may most conveniently be separated into five great Divisions known respectively as the THALLOPHYTA, BRYOPHYTA, PTERIDOPHYTA, GYMNOSPERMÆ and ANGIOSPERMÆ.

These five Divisions are very large, and further subdivision into smaller groups containing those plants which are more nearly allied is necessary, the groups again being sub-divided.

Species.—The new individuals which are produced from the seeds of any particular plant resemble each other very closely, and also their parents, and in like manner their

descendants will also present the same characteristic resemblances. All plants which possess this very close degree of similarity, and which have the greatest number of characters in common, may be considered to have descended from a common ancestor, and constitute what is termed a *species*. The main characters of a species are constant, but admit of slight variations, which though permanent, are insufficient to characterize a new species, and plants possessing them are described as *varieties*.

Genus.—Species which very closely resemble each other, and are therefore related, are grouped into a *genus*, which is marked by the characters common to all the species. In assigning a name to any plant it is necessary that there should be two, one to indicate the genus and the other the species, the generic name always standing before the specific one. As an illustration we may cite the genus *Triticum* (Wheat) which comprises the several kinds of Wheat, Couch-grass etc.; these all agree in having the *spikelets solitary, many flowered, and arranged without stalks, broadside on a central axis*, and are bound together by these characters. It is very evident however that the various species of this genus differ greatly from each other, as each species has certain definite characters of its own. Thus, all the members of this genus with *creeping subterranean stem, spikelet of about five flowers, pointed glumes and short awns*, belong to the species *repens* and are therefore known as *Triticum repens*.

The cultivated Wheats can all be reduced to seven species, these however vary to such an extent that over 300 varieties are known.

Just as Species are grouped into Genera, so Genera are grouped into Orders, the characters of the Order being in

the same way the characters common to the Genera. The Orders are similarly grouped into Cohorts and the Cohorts into Series, the Series into Sub-classes, these again into Classes, and the Classes into Divisions.

A Couch-grass, then, may be placed in its proper position thus:

Species . . .	repens
Genus	Triticum
Order	Gramineæ
Cohort	Glumales
Series	Glumifloræ
Sub-Class . . .	Nudifloræ
Class	Monocotyledones
Division . . .	Angiospermæ

THALLOPHYTA.—This division comprises all those plants whose vegetative system consists merely of a *thallus*, that is a structure in which the cells are not differentiated into the three tissue systems, and in which therefore there is no division into stem, leaf, and root. These plants may consist of a single cell, or of a thread-like row of cells (filament), or of a cellular expansion (cell-plate), in which forms all the cells are exactly similar. Some of the higher forms however are larger and more complex, and in these, structures resembling the members of the higher plants may be found.

This Division is separated into two main Classes, the *Algæ* and the *Fungi*.

The Algæ are green and possess chlorophyll.

The **Fungi** are destitute of chlorophyll. The more important, which have any direct bearing upon agriculture, have already been considered in relation to disease.

The **BRYOPHYTA** embrace the Mosses and Liverworts.

The **PTERIDOPHYTA**, also known as **Vascular cryptogams**, include the Ferns and their allies. These plants are much higher in the scale than Mosses and are the lowest group which have true stem, leaves and roots, all these members possessing epidermis, ground, and fibro-vascular tissue.

In this Division there are two distinct generations; one, the larger, with stem, leaf and root, which bears only spores and is therefore an asexual generation; and the other, much smaller—*prothallium*—a mere cellular expansion which bears the sexual organs. These two generations regularly alternate with each other, the asexual generation arising from the fertilised oosphere, and the prothallium being always produced from the germination of a spore. Alternation of generations although well-defined in this Division is not confined to it, and may be traced from the Bryophyta to the Angiospermæ.

In the *Equisetums*, which belong to this Division, the spores are developed on special modified leaves arranged in cones at the end of the aerial stems. Sometimes these cones terminate the ordinary vegetative shoots or they may be borne on special branches. In the case of the Horsetail (*Equisetum arvense*), these latter may be found about Easter, that is before the vegetative shoots appear, projecting about an inch or so above the ground. The spores are all exactly similar; and being armed with four long and slender projections (*elaters*) are easily distributed by the wind. The Horse-tail is a well known plant found on Railway embankments, in hedgerows, and often in arable land, in which it is a troublesome weed. It has both an underground and an aerial stem, the former penetrating to great depths renders its extermination a matter of some difficulty.

The first three Divisions are sharply distinguished from the other two by the fact that they never have flowers, nor produce seed, the production of flowers and seeds being the special characteristics of the Gymnosperms and Angiosperms.

GYMNOSPERMÆ.—In this Division the carpel never encloses the ovule, which is therefore exposed to the air, so that the pollen is placed directly upon the micropyle. The endosperm is formed before fertilization takes place.

This Division comprises three Orders, the largest of which, the Coniferæ, embraces many plants growing in this country, such as the Fir, Larch, Pine, Yew, Juniper, etc.

Yew poisoning.—Many authentic cases are recorded in which Horses, Cows and Sheep have eaten the leaves and shoots of the Yew, and have died from the effects of its poisonous properties. But beyond the fact that the Yew is poisonous, little more appears to be known. The seeds of the Yew are green, and enclosed in a red or yellow juicy cup—the *aril*. The aril is frequently eaten by children, and greedily devoured by birds without any ill effects, and cannot therefore contain poison; but the seeds are said to be poisonous, though in a less degree than the leaves and shoots.

ANGIOSPERMÆ.—The Angiosperms are distinguished from the Gymnosperms by having the ovules always surrounded and protected by the carpel. This necessitates the formation of the style and stigma, the pollen grain being placed on the stigma. Another characteristic is that the endosperm is not formed until after fertilisation has taken place.

The Division is separated into two Classes, the Mono-

cotyledons and the Dicotyledons, which are distinguished by several characteristics.

The MONOCOTYLEDONS have no cambium, so that the fibro-vascular bundles of the stem and root are closed. These members therefore cannot increase in thickness. In the leaf the venation is parallel, exceptions being found only in a few cases, as the Arums, etc. The parts of the flower are generally in threes, or a multiple of this number, the typical flower having 3 petals, 3 sepals, 6 stamens, 3 carpels. The embryo has only one cotyledon. Examples, —Grasses, Sedges, Lilies, Rushes, Palms, etc.

For the purpose of classification the Monocotyledons may be divided into the **Nudifloreæ**, or those destitute of calyx and corolla, and the **Petaloideæ**, whose flowers have at least one series of these members, which is very often showy and conspicuous. This classification is not truly scientific, but is convenient as a method of separating the plants into groups.

Sub-Class I.—**Nudifloreæ** is again divided into two Series.

In the first, **Spadicifloreæ**, the flowers are enveloped in a leaf known as a *spathe*. This series is a very large one, and comprises the Pond-weeds, Arums, Palms, etc.

The second Series, **Glumifloræ**, in addition to some tropical Orders includes the Grasses and Sedges.

CYPERACEÆ—The Sedges, are grass-like plants, but can at once be distinguished by the solid stem, which is generally triangular, and by the leaf-sheath which is much shorter than in the true Grasses, and is not split. Ligules too are absent. The flowers are unisexual (or sometimes hermaphrodite), and arranged in spikes. The

staminal spikes, in the upper portion of the inflorescence, contain a large number of flowers which are destitute of perianth, and each consists usually of 3 stamens. The pistillate flowers are composed of three carpels, united into a one-seeded, one-chambered pistil, which in the unisexual flowers is enclosed in a bract.

The Sedges are very common, some species living on the banks of streams and in bogs, while others are confined to downs and pastures. They vary in height from an inch or two, to 1-2 feet.

GRAMINEÆ.—This Order is easily recognised by the fibrous roots, hollow round stems with solid swollen nodes, leaf with split sheath and ligules, flowers arranged in spikelets, stamens 3, carpels 2, ovary unilocular with only one ovule, wall of carpel adhering to seed, embryo lateral and not enclosed by the endosperm.

Sub-Class II.—**Petaloideæ** is divided into two Series.

Series I.—**Hypogynæ** has the ovary always situated above the perianth.

The APOCARPÆ, a section of this Series, is distinguished by the carpels all being separate from each other. It includes many water plants, as the Water-plantain, Arrowhead, Flowering-rush.

The SYNCARPÆ, another section, is distinguished by the carpels being united. This includes the Lilies and Rushes.

LILIACEÆ is characterised by all the segments of the perianth being coloured; by the six stamens, and the superior 3-chambered ovary of 3 carpels.

Useful plants belonging to this Order are:—

Allium cepa—The Onion, (fig. 22); *Allium porrum*—The Leek; *Allium ascalonicum*—The Shallot; *Allium*

sativum — The Garlic; *Hyacinthus* — Hyacinth; *Scilla nutans* — Blue-bell; *Tulipa* — Tulip; *Lilium* — Lily; *Aloë*—the Aloe.

Series II.—**Epigynæ** has the ovary below the perianth, which therefore appears to spring from the top of the ovary. This Series includes the Iris, Snowdrop, Gladiolus, Black-bryony, the Orchids.

The DICOTYLEDONS have cambium, and the stem and root are thus capable of increase in thickness. The leaves have reticulate venation. The parts of the flower are in fours or fives, and there are two cotyledons. The majority of our common trees and flowers belong to this Class.

In England, following the classification of A. L. de Jussieu (1789), the Dicotyledons are divided into three principal Sub-classes—namely:—

Polypetalæ or those plants like the Buttercup, Wall-flower etc., which have their petals all distinct from each other.

Gamopetalæ in which the petals are united with each other, and form corollas of the most varied shapes, *e.g.*, Foxglove, Snapdragon, Canterbury-bell.

Apetalæ which possess flowers having either stamens or pistil, but generally neither calyx or corolla, though sometimes one of these series is present. Examples are found in Oak, Hazel-nut, Rhubarb, Nettle, etc.

These divisions, although convenient, are by no means scientific, for one character only is thus made to serve as a basis of classification. At the time it was proposed, this system was a marked advance upon those which preceded it, but more recent investigations have shown that such a sharp line does not exist between these Sub-classes; and

many plants which on account of the structure of their flowers should be placed among the Apetalæ, are really allied to members of the other Sub-classes and must be distributed among them. This classification therefore in practice cannot be strictly maintained, and the Apetalæ now contain only those plants without calyx and corolla whose affinities are doubtful.

In considering the further sub-divisions, the classification of Hooker and Bentham is adopted, and, as before, only the more important Orders will be dealt with.

The **Polypetalæ** are divided into three series.

Series I.—**Thalamifloræ**.

The members of the flower are all distinct from one another, each one arising above the other without becoming joined to it.

RANUNCULACEÆ—Recognized by the indefinite stamens, and the carpels all distinct from each other. 15 genera.

Ranunculus—Buttercup, Crowfoot, etc., has five sepals, and five petals each with a nectary at its base.

R. arvensis is an annual plant and a common weed in cornfields; it has a brown fruit bearing a number of spikes.

R. acris; R. repens; R. bulbosus are all found in pastures and known as Buttercups.

R. ficaria, found in hedge-banks and fields, is the Pilewort.

The remaining important plants of this order are *Clematis* (Traveller's Joy); *Anemone; Caltha* (Marsh Marigold); *Helleborus* (Hellebore); *Aquilegia* (Columbine); *Delphinium* (Larkspur); *Aconitum* (Aconite).

BERBERIDEÆ—One carpel, 6-9 stamens.

Berberis vulgaris—the Common Barberry, is found in hedges, and is often grown in gardens, attaining a height of about 12 feet. The stamens are very irritable, and when touched, close round the pistil, with the object of dusting with polen, not the stigma, but the body which touches them. In this way bees which settle on the flower are covered with pollen.

This shrub is one of the hosts of *Puccinia graminis.*

PAPAVERACEÆ—Herbaceous plants exuding a milky juice when bruised. Sepals caducous *i.e.*, falling away as the flower opens. Petals double the number of sepals. Stamens indefinite, carpels united to form an ovary with one chamber, on the summit of which the Stigmas are seen as dark radiating lines. 5 genera.

Papaver—Poppies. Four species are found in Corn-fields, and are weeds of cultivated ground.

P. hybridum is known by its round and prickly fruit; *P. argemone* has also a prickly fruit but much larger than that of *P. hybridum; P. dubium* has a long smooth fruit, by which it is distinguished from *P. rheas*, the common field Poppy, whose fruit is smooth, but round.

P. somniferum is the Opium Poppy.

FUMARIACEÆ—Corolla irregular, petals double the sepals, stamens two, each with three anthers.

Fumaria—Fumitory. Four species are common weeds in cornfields and arable lands.

CRUCIFERÆ—Two sepals, four petals, six stamens of which the two lateral are shorter than the four median ones, two carpels united, the ovary divided into two chambers by a partition known as the *replum.* To allow the seeds to escape, the two sides of the ovary fall off, and leave the seed attached to the replum; a very familiar instance of this

may be observed in "Honesty," so frequently preserved on account of the pretty effect of its silvery-white replum. The fruit of this Order is known as a *siliqua*. The seeds have no endosperm.

Brassica—Calyx erect, fruit long, angular and produced into a terminal beak.

This is the most important genus of the Order and supplies very many useful plants.

B. oleracea—The Wild Cabbage. The upper leaves are without stalks, the lower lyrate and wavy, covered with bloom. It is from the cultivation of this plant that all the many varieties of Cabbage have been derived; it is a biennial, from 1-2 feet, and is found growing wild on the cliffs of the South and West Coasts.

B. oleracea		*capitata*	—the Common Cabbage
,,	,,	*rubra*	—the Red Cabbage
,,	,,	*botrytis cauliflorœ*	—the Cauliflower
,,	,,	*botrytis asparagoides*	—the Broccoli
,,	,,	*bullata*	—the Savoy
,,	,,	*gemmifera*	—Brussel Sprouts
,,	,,	*caulorapa*	—Kohl-rabi
B. rapa			—the Turnip.
B. campestris rutabaga			—the Swede.
B. napus			—the Rape.

In the Kohl-rabi the lower portion of the stem, and in the Turnip and Swede the roots, are enlarged to serve as reservoirs of reserve material, and hence are largely grown for food.

Sinapis—Sepals spreading, pods linear with beak.

S. arvensis — Charlock, or Runches, is a common

annual, and troublesome weed on arable land. It has bright yellow flowers.

S. alba—White Mustard, and *S. Nigra*—Black Mustard, are commonly cultivated.

Raphanus—pods tapering and divided into one-seeded joints.

R. rapanistrum is the Wild Radish, an annual weed on arable land.

R. sativum—the garden Radish, is not a native of this country, although extensively cultivated for the sake of the root, which is a reservoir of reserve material.

The Order Cruciferæ is a large one including many other useful and ornamental plants, among which we may mention.

Crambe maritima (Sea Kale); *Iberis amara* (Candytuft); *Lepidium sativum* (Cress); *Cochlearia Armoracia* (Horse-radish); *Nasturtium officinale* (Water-cress); *Sisymbium officinale* (Hedge-Mustard); *Cheiranthus cheiri* (Wall-flower); *Matthiola* (Stock).

VIOLACEÆ—The Pansies and Violets. One genus.

Viola tricolor is a common annual weed in fields.

POLYGALACEÆ — Flowers irregular, two lateral sepals, large and coloured, ovary two chambered. One genus.

Polygala vulgaris—Milk-wort, is a very common plant in pastures. Its flowers are either pink, white, or blue.

CARYOPHYLLACEÆ — Stem herbaceous, with swollen nodes; leaves simple, entire, opposite; sepals and petals five; stamens 8-10; ovary one-celled. Seeds with endosperm. Thirteen genera.

The plants of this Order are for the most part weeds, though some are cultivated for the sake of their brilliant flowers.

Lychnis vespertina—White Campion; *L. diurna* (Red Campion); *L. flos-cuculi* (Ragged Robin) are all perennial weeds. *L. githago* (Corn-cockle) (fig. 32) is an annual weed very common among cereals; its seeds are liable to be harvested with the crop, becoming then an impurity, and damaging the sample of the grain.

Dianthus—Pink and Carnation.

Spergula arvense—Spurry, common on sandy lands, is sometimes cultivated.

Stellaria (Stitchwort). *Cerastium* (Chickweed).

Series II.—**Discifloreæ.**

The floral axis is swollen inside the sepals to form the nectary, the petals and stamens being inserted around or upon the disc.

Note.—In the Linaceæ and Geraniaceæ, the disc is small and reduced to a number of nectaries at the base of the stamens.

LINACEÆ—Herbs with simple exstipulate leaves, sepals persistent, petals twisted in the bud, fruit 3-5 celled.

Linum usitatissimum—The Flax, 1-2 feet high, with blue flowers. It is cultivated for the bast fibres which are obtained from the stems by maceration, and manufactured into linen. The seeds are albuminous, and when crushed yield linseed oil, while the residue is used for linseed cake.

L. catharticum—Purging Flax, is a small annual plant common in fields, 2-10 inches.

GERANIACEÆ — Sepals five, persistent; carpels five arranged round a long beak, from which they spring elastically and eject the ripe seed to considerable distances.

Geranium pratense—Blue Meadow Cranesbill, a handsome plant, is found in meadows.

P

G. robertianum—Herb Robert, common in hedge banks. Several other species are annuals and weeds in cornfields.

Series III.—**Calycifloræ.**

The apex of the floral axis is hollowed to form a cup, on the margin of which the sepals, petals, and stamens are inserted; an appearance is thus given as if the petals and stamens were inserted on the calyx, and hence the name. The receptacular cup may be free or may be fused with the ovary.

LEGUMINOSÆ. (Chapter xii.)

ROSACEÆ—Trees, shrubs or herbs. Leaves often compound, stipulate; sepals 5; petals 5; stamens numerous; carpels distinct from each other. A very large Order, comprising many plants which bear valuable fruits. 17 genera.

Prunus—Plum, Cherry, etc. In the flowers of this genus there is one carpel, which ripens into a fleshy fruit (*drupe*); a hard stone, formed from the inner wall of the carpel, serves to protect the seed, (*kernel*), the rest of the carpel being succulent.

Fragaria—Strawberry. The extremity of the floral axis enlarges, and becomes the edible part of the Strawberry, upon which the carpels are found as small brown nuts, the so-called seeds.

Rosa—Rose. The hollow floral axis bears the sepals, petals, and stamens, at its edge, and numerous carpels on its inner surface; on ripening, it becomes succulent to form the Hip.

Rubus— Blackberry, Raspberry. Each carpel ripen into a minute drupe.

Pyrus—Apple, Pear. The receptacular cup enlarges,

and fuses with the carpels to form the Apple or Pear. These are therefore not true fruits.

Cydonia—Quince. Fruit the same as the Apple.

Cratægus—Hawthorn. Fruit the same as the Apple..

Among other common plants belonging to this Order may be cited,—*Sanguisorba officinalis* (Greater Burnet), and *Poterium sanguisorba* (Lesser Burnet), common in meadows. The flowers are clustered into deep red heads, and are destitute of petals. *Spirea* (Meadow Sweet); *Geum* (Avens); *Potentilla*; *Alchemilla* (Ladies-mantle).

CUCURBITACEÆ—Chiefly climbers. Flowers unisexual, sepals 5, petals 5, stamens 3, carpels 3, ovary inferior.

Bryonia dioica—White Bryony, is the only native species. The various kinds of Melon, Pumpkin, Vegetable Marrow, Cucumber, and Gourd, all belong to this Order. They are cultivated for the sake of the fruit, which often attains a considerable size.

UMBELLIFERÆ—Herbs, with hollow stems, and compound leaves with large sheaths. Inflorescence a simple, or more generally a compound umbel, sepals often absent, petals and stamens 5, carpels 2, each with only one ovule, ovary inferior. The fruit, technically known as a *cremocarp*, splits when ripe into two halves (*mericarps*), each containing one seed. The mericarps are sometimes flat and thus easily distributed by the wind, or hooked, and are then dispersed by animals.

Conium maculatum—Hemlock, a large plant, growing from 2-4 feet high, found on hedge banks. It may easily be recognised by the purple spots on the stem, the large compound leaves, and small wrinkled compressed fruit. The Hemlock is very poisonous.

Apium graveolens—Celery, a small plant found in

marshes, is the plant from which the garden Celery has been derived. It may be recognised by the leaves which are ternate, the lobes of the lower ones entire, while those of the upper ones are notched. The umbels, too, have very short stalks.

Petroselinum sativum—Parsley, is a native plant found growing on old walls, and attaining a height of 1-2 feet.

Ægopodium podagraria—Gout-weed, is often a troublesome weed in gardens. It prefers damp or shady situations.

Carum carui—Caraway, is sometimes grown for Caraway "seeds," which are in reality, fruits. It may be found wild in waste places, growing from 1-2 feet high.

Bunium flexuosum—The Earthnut, is a common plant with a tuberous root.

Œnanthe flexuosum—Water-dropwort. In this genus there are 8 native species found growing in ditches or in marshy districts, all of which are poisonous.

Æthusa cynapium—Fool's Parsley, is an annual, about 1½ feet high. It is a common plant in waste places, becoming a weed of arable land.

Fœniculum vulgare—Fennel, found wild on cliffs.

Pastinaca sativa—Parsnip, it occurs wild in chalky districts, and is the parent of the garden Parsnip.

Heracleum spondylium—Cow-parsnip, or Hog-weed, a rough plant, from 4-5 feet, found in meadows and waste places.

Daucus carota—Carrot, occurs in chalky districts, and is the wild form from which the garden Carrot has been derived.

Torilis infesta—Spreading Hedge-parsley, has its fruits covered with hooked bristles. It is a small annual, from 4-12 inches, a common weed in cornfields.

Scandix pecten-veneris—Shepherd's-needle, has a very long pointed fruit. It is a common weed in cornfields, from 4-12 inches high.

Anthriscus—Beaked Parsley.

A. vulgaris and *A. sylvestris* are common wayside plants from 2-4 feet high.

Chærophyllum temulum—Rough Chervil, a common wayside plant with the stem nodes swollen.

The **Gamopetalæ** are divided into 3 Series.

Series I. **Epigynæ.**—Ovary inferior.

RUBIACEÆ — Herbs with leaves arranged in whorls, flowers regular, stamens equal the petals, carpels two. 4 genera.

Galium verum is the Bedstraw. *G. aparine*—Cleavers, or Hariff—a common plant in hedges, has its stem and fruit covered with hooks, the former to help it in climbing, the latter to distribute the seeds. It is a very mischievous weed in cornfields, for when harvested with the crop, it sometimes renders it almost worthless.

COMPOSITÆ—Herbaceous plants with alternate leaves. Flowers usually small and aggregated on a receptacle to form a head or capitulum, surrounded by a number of green bracts; calyx absent or reduced to a number of hairs, the pappus; corolla, five petals united to form a tubular or strap-shaped corolla; stamens equal to the petals; anthers form a tube surrounding the style: carpels 2; style single, branching into a two-armed stigma; ovary unilocular, one-seeded. This Order is the largest among the Angiosperms, it is widely distributed throughout the globe, in a great measure owing to the ease with which

the fruits are dispersed by the wind. As an example, we may cite the familiar Thistle-down which is blown every where by the wind. In this country there are forty-five genera belonging to this Order, a few of which are useful, many are weeds.

Bellis perennis—the Daisy.

Gnaphalium uliginosum—the Cud-weed, is a common annual weed on arable land.

Anthemis—Chamomile.

A. nobilis (perennial), *A. arvensis* and *A. cotula* (annual) are very common weeds. This genus may be distinguished by the scaly receptacle.

Chrysanthemum—Ox-eye.

C. segetum (annual) has yellow flowers, and is a common weed, especially on sandy lands.

C. leucanthemum (perennial) has large white flowers, and is common on railway banks and in meadows.

Matricaria—Wild Chamomile or Feverfew.

M. parthenium (perennial), *M. inodora* (annual), and *M. chamomilla* (annual), are common weeds in cornfields. *Matricaria* and *Anthemis* very much resemble each other, but *Matricaria* has a conical receptacle and bracts without scarious margins.

Tussilago farfara—Colts-foot, is a common perennial weed. It has two kinds of stems, (1) the vegetative which is almost entirely subterranean, bearing only a few angular foliage leaves just above the surface of the soil; and (2) special reproductive stems, produced in the spring before the leaves appear, which arise from the apex of the underground stem. These reproductive stems are only an inch or so in height, and bear capitula of bright yellow flowers. This plant is widely distributed by means of its hairy fruits.

Senecio vulgaris—the common Groundsel, is a very troublesome annual weed.

Cnicus and *Carduus*. The species of these two genera are commonly known as Thistles.

Cnicus lanceolatus is the common spear Thistle; *C. arvensis* the creeping Thistle; and *C. palustris*, another common Thistle, growing often to a great height, and preferring moist or wet situations.

Centaurea—Knap-weed.

C. nigra—Hard-head, Black Knap-weed, is a common plant with purple flowers.

C. cyanus is the Corn Blue-bottle often grown in gardens.

Cichorium intybus—Chicory or Succory, is a common perennial, with blue flowers. The roots of the cultivated chicory are used for mixing with coffee.

Crepis (Hawk's-beard) and *Hieracium* (Hawk-weed), are common weeds often found in meadows.

Taraxacum officinale is the common Dandelion.

Lactuca—Lettuce.

L. sativa is the garden Lettuce.

Sonchus—Sow Thistle.

The three species *arvensis* (perennial), *asper* and *oleraceus* (annuals), are common weeds.

Tragopogon—Goat's-beard.

T. porrifolius (Salsafy) is grown on account of the edible roots.

Series II. **Heteromeræ.**—Ovary superior, carpels more than two.

PRIMULACEÆ—Herbs, easily recognised by the stamens and ovary, the former being five, that is, equal to the petals,

and placed opposite to them; the ovary having a central axis on which the ovules are placed.

Primula vulgaris is the common Primrose.

P. veris the Cowslip.

Anagallis arvensis, a small plant with bright red flowers, is the Pimpernel or "Poor-man's weather-glass.

Series III. **Bicarpellatæ**. — Ovary superior, carpels two.

BORAGINEÆ—Herbs, often with very hairy alternate leaves, and stems: five sepals; five petals, uniting to form a regular corolla; five stamens. Attached to the petals, between each stamen, there is a tongue-like outgrowth from the petals, partially closing up the corolla. Ovary, two carpels each divided so that the ovary is 4-lobed, the style arising from between the lobes at their bases; each lobe contains 1 ovule, and the fruit when ripe separates as four nutlets.

Symphytum officinale—Comfrey, is a white-flowered herb, generally preferring banks of rivers or streams.

S. asperrimum is the Prickly Comfrey, cultivated for the sake of its leaves, which are a useful fodder for cattle.

Borago officinalis—Borage, is commonly grown in gardens.

Myosotis—Forget-me-not, Scorpion-grass.

M. arvensis, a common annual weed in cornfields.

M. palustris—The Forget-me-not.

Echium vulgare—Viper's Bugloss (biennial), is a weed frequently found in chalky fields.

CONVOLVULACEÆ — Herbs. Stem subterranean and aerial, the latter climbing by twining round other plants. Flowers regular, funnel-shaped.

Calystegia sepium—White Convolvulus (Greater Bindweed), is a very pernicious weed in gardens, the white

underground stems sending up aerial stems, which twine round and smother the crop. The plant is very difficult to exterminate, the smallest piece of an underground stem serving to raise a new plant.

Convolvulus arvensis—Bind-weed, is much smaller than the last named, but with a very similar habit.

Cuscuta—Dodder (fig. 98). Stems pinkish white, filiform, without chlorophyll, and bearing no leaves. Flowers small and inconspicuous, pale pink, borne in clusters on the stem; sepals 5, persistent; petals 5, with 5 scales between the stamens; carpels 2; styles 2; ovules 4. Embryo coiled round the endosperm.

The Dodder is a plant to which allusion has previously been made, as being devoid of chlorophyll, and thus unable to assimilate its own food materials, obtaining its nutriment after the manner of a fungus. There are four species in this country which prey upon a number of plants, among which are Clover, Hop, Nettle, Flax, Whin and Heather.

On the germination of the seed the embryo emerges as a whip-like filament (see lower right hand corner of fig. 98), yellowish white, which by means of a sticky secretion is able to attach itself to any plant with which it may come in contact. It then immediately produces suckers (*haustoria*), i.e., special outgrowths which penetrate the stem of the host-plant, and unite with its tissues, so that the wood and bast vessels of the parasite become continuous with those of its host. By this means the Dodder draws its supplies, and soon puts forth larger and stronger stems which, twining round the stems and leaves of the host, develop suckers at the points of contact. Continuing to produce fresh branches it gradually envelops and exhausts its host, and spreads with great rapidity to neighbouring plants.

In the Clover field, Dodder often causes great destruction to the crop. Its attack presents many analogies with that

Fig. 98 (*from Krafft*).
Dodder (*Cuscuta trifolii*) parasitic upon Red Clover. The upper figure on the left is a stem with haustoria and cluster of flowers; *in the lower right hand corner are two embryos just* free from the seed; *c*, embryo emerging from seed.

of the Fungi, with this difference, however, that the workings of the Dodder are plainly to be perceived, while

those of the Fungi are invisible to the naked eye. The only remedy in this case also is the destruction of the parasite, which is only accomplished by destroying the plant attacked, and obviously the greatest care should be exercised in ensuring that no Dodder seeds are sown with those of the Clover.

SOLANACEÆ — Herbs with alternate leaves; flowers regular, sepals, petals, and stamens 5; ovary two-celled and many ovuled, often subsequently becoming four-celled, and ripening into a berry.

Solanum dulcamara—Bitter-sweet, a common plant in hedges, with red poisonous berries.

S. nigrum is a small plant with white flowers, an annual weed in gardens.

S. tuberosum—The Potato.

Atropa belladonna—The Deadly-nightshade, one of the most poisonous of British plants. It is a shrub, from 2-4 feet high, with solitary bell-shaped flowers of a dull purple hue, and large black berries.

SCROPHULARIACEÆ—Herbs, with alternate leaves; flowers irregular; stamens 4; fruit a many-seeded, 2-celled capsule.

Antirrhinum—The Snapdragon.

Digitalis—Foxglove.

Veronica—Bird's-eye, Speedwell. Flowers blue, 4 unequal petals, 2 stamens.

Rhinanthus—Yellow Rattle, a very common weed in meadows; *Melampyrum* (Cow-wheat); *Bartsia*; and *Euphrasia* (Eye-bright) are semi-parasitic, that is, although having green leaves, they attach their roots to those of Grasses, and deprive them of the food substances absorbed from the soil.

LABIATÆ — Herbs. Stem square; leaves opposite;

flowers irregular, clustered in the axils of the leaves; stamens 4. The structure of the ovary exactly resembles that of the Boragineæ, but the opposite leaves, irregular flowers, 4 stamens and bifid stigma easily mark this Order.

Prunella vulgaris—Heal-all, is a common weed in pastures; *Mentha*—Mint; *Thymus*—Thyme; *Salvia*—Sage; *Lamium*—Dead nettle, are also members of this Order.

PLANTAGINEÆ — Herbs; leaves quite close to the ground; flowers in spikes; calyx 4; petals 4, scarious; stamens 4; ovary many seeded.

The Plantain or Rib-wort is very common and conspicuous, its rosette of leaves lying close to the ground, from the centre of which the stalk bearing the inflorescence arises. The Plantains are very common in lawns, their leaves easily spreading over and killing the grass near them.

Apetalæ.

CHENOPODIACEÆ — Herbs, with alternate leaves often covered with small glandular hairs, which give them a mealy feel to the touch, especially in the younger stages. Flowers small, sometimes unisexual; sepals five; corolla absent; stamens opposite sepals; ovary, one-celled, one-ovuled; embryo generally coiled round the endosperm (fig. 99, *e.*)

Beta—Perianth persistent, remaining closely attached to the fruit. The "seeds" of the Beet are therefore fruits, with adherent sepals (*b.*).

B. vulgaris (fig. 99)—The Common Beet, a native of the South of Europe, was extensively cultivated by the Romans.

B. maritima may be found wild on our coasts. From its cultivation the garden Beet, and the different varieties of the Mangold Wurzel have been produced.

Spinacia oleracea—Spinach, introduced into Spain by the Arabs, and thence has spread over Europe.

Chenopodium bonus henricus (Good King Henry) (perennial), and *C. album* (Goosefoot or Fat-hen) (annual), are very common weeds.

POLYGONACEÆ — Herbs, characterised by the stipules which clasp the stem and are known as the *Ocrea*. Flowers small: sepals 3-6; stamens 5-9; ovary one-celled, one-seeded; fruit usually winged, triangular, indehiscent.

Fig. 99 (*from Nobbe*).

Beet (*Beta vulgaris*); *a*, portion of inflorescence with flowers; *b*, fruit partially enclosed by sepals; *c*, fruit; *d*, seed; *e*, longitudinal section of seed, α radicle, β seed leaves, γ endo-sperm.

Rheum — Rhubarb, is the most important genus. It is a native of the Central and Eastern parts of Asia, and has been introduced Westwards.

Polygonum—Various species of this genus are weeds.

P. aviculare (Common Knot-grass) is a troublesome annual weed.

P. convolvulus—(Climbing Knot-grass) an annual weed,

frequently found in cornfields twining up the stems of cereals.

P. fagopyrum—Buckwheat, is commonly grown in the Eastern Counties, its fruit serving as food for Pheasants and Poultry.

Rumex acetosa (the Sorrel) and *R. acetosella* (Sheep's-sorrel) are common plants, the latter often a troublesome weed.

The other species of *Rumex* are familiarly known as Docks.

URTICACEÆ—Herbs, provided with stinging hairs upon the stems and leaves. Flowers unisexual, clustered together. The stamens which are rolled up in the bud, straighten with a jerk, and thus scatter the pollen. Ovary one-celled, one-ovuled.

Urtica urens and U. dioica are the common Stinging-nettles.

Humulus lupulus—The Hop.

Ulmus—The Elm is generally included in this Order; its stamens, however, are not explosive.

EUPHORBIACEÆ—Herbs, with a milky juice. Flowers uni-sexual, consisting of either one stamen, or of a three-celled ovary. These very simple flowers are clustered together, and surrounded by a cup of 4-5 leaves. The species of *Euphorbia* (Spurge) are common annual weeds.

E. lathyris is the Caper.

Buxus—The Box tree; and *Mercurialis*—Dog's Mercury, belong to this Order.

CUPULIFERÆ—Oaks, Hazel, Alder, Beech, Birch.

SALICINEÆ—Willows.

APPENDIX.

NOTE ON THE FORMATION OF STARCH.

THE account of the manufacture of starch on pages 56-60 s mainly derived from the various researches of Sachs; but since the above was written additional and important information on the assimilation of leaves has been recently published by Messrs Brown and Morris ("A Contribution to the Chemistry and Physiology of Foliage Leaves," *Journal Chem. Soc.*, May 1893). The researches of these authors confirm the view that the starch in the chlorophyll corpuscles is not the first product manufactured during assimilation, and, further, give very strong evidence that the first product of assimilation is *cane sugar*. They show that though "Starch is the first visible product of assimilation, yet there can be little doubt (as was, in fact, anticipated by Sachs himself) that between the inorganic substances entering into the first chemical process of assimilation and the starch, there is a whole series of substances of the sugar class, and that it is from the last members of this series that the chloroplasts, under normal conditions, elaborate their starch. Both under the natural conditions of assimilation and the artificial conditions of nutrition with sugar solutions, the chloroplasts form their included starch from antecedent sugar." The starch deposited in the chlorophyll corpuscles appears to be merely a temporary reserve material, only formed in the cell when the amount of its assimilated products is beyond that required for immediate use, or when the sugar solution has reached a certain degree of concentration.

By a series of very interesting experiments and calculations Messrs Brown and Morris have shown that the leaf is continually losing its assimilated products, but that under favourable conditions of sunlight, the rate of depletion is less than the rate of assimilation, and in an experiment with the Sunflower (*Helianthus annus*) the excess of assimilation over depletion was ·713 grams per sq. m. per hour, on a bright August day. The amount of increase in weight due to assimilation was found to be one gram per sq. m. per hour; but the amount of starch formed under the same conditions, as determined by another experiment, was ·12 grams per hour.

The dissolution of the starch is another matter of great interest. The authors have demonstrated the occurrence of diastase in leaves, in sufficient quantity to render soluble all the starch in the leaf, and the dissolution of starch is thus mainly due to the action of *diastase*. With reference to the particular form in which the carbohydrates pass from cell to cell, the analyses of Messrs Brown and Morris point to the fact that the cane sugar is transferred as dextrose and levulose, and the starch as maltose.

NOTE ON THE POTATO DISEASE.

Dr J. Boehm, in a recent paper (*Sitzungsberichte d. k.k. Zoolbot. Gesellschaft in Wien. Bd. xlii.*), has thrown some doubt upon the assertion that the mycelium of *Phytophthera infestans* hibernates in the Potato tuber, and gives his opinion that the mode in which this fungus passes the winter is entirely unknown. He states, as the result of his numerous investigations, that a Potato infected with *Phytophthera* either develops a sound plant or produces no plant at all; that infection can only take place on bruised spots, and healthy Potatoes are never infected by unsound ones.

NOTE ON RUST OF WHEAT.

Puccinia graminis most frequently attacks the Wheat and Rye, and in a less degree Barley and Oats; but it may also often be found upon many other Grasses (*Sweet Vernal, Couch-grass, Meadow Fox-tail, Cat's-tail, Bent, Quaking-grass, Cock's-foot, Yorkshire Fog, Perennial Rye-grass*, and many others). In some of these (*Fox-tail, Cat's-tail, Quaking-grass, Yorkshire Fog*) the mycelium produces "Summer-spores" through the entire year, either exclusively or in addition to the "Winter-spores." The fungus, therefore, is able to hibernate in these Grasses, and in the following spring to distribute itself by means of Summer-spores. This explains the presence of "Rust" in localities where no Barberry-bushes are found; and also that the extermination of the Barberry checks but may not stamp out the disease, for the fungus hibernating in the manner described is able to persist without completing the entire cycle.

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